The Handbook of Environmental Chemistry 56
Series Editors: Damià Barceló · Andrey G. Kostianoy

Abdelazim M. Negm *Editor*

The Nile River

Springer

The Handbook of Environmental Chemistry

Founded by Otto Hutzinger

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Volume 56

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The Nile River

Volume Editor: Abdelazim M. Negm

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Springer

Editor
Abdelazim M. Negm
Faculty of Engineering, Department of
Water and Water Structures Engineering
Zagazig University
Zagazig, Egypt

ISSN 1867-979X ISSN 1616-864X (electronic)
The Handbook of Environmental Chemistry
ISBN 978-3-319-59086-8 ISBN 978-3-319-59088-2 (eBook)
DOI 10.1007/978-3-319-59088-2

Library of Congress Control Number: 2017942724

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer International Publishing AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

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Aims and Scope

Since 1980, *The Handbook of Environmental Chemistry* has provided sound and solid knowledge about environmental topics from a chemical perspective. Presenting a wide spectrum of viewpoints and approaches, the series now covers topics such as local and global changes of natural environment and climate; anthropogenic impact on the environment; water, air and soil pollution; remediation and waste characterization; environmental contaminants; biogeochemistry; geo-ecology; chemical reactions and processes; chemical and biological transformations as well as physical transport of chemicals in the environment; or environmental modeling. A particular focus of the series lies on methodological advances in environmental analytical chemistry.

Series Preface

With remarkable vision, Prof. Otto Hutzinger initiated *The Handbook of Environmental Chemistry* in 1980 and became the founding Editor-in-Chief. At that time, environmental chemistry was an emerging field, aiming at a complete description of the Earth's environment, encompassing the physical, chemical, biological, and geological transformations of chemical substances occurring on a local as well as a global scale. Environmental chemistry was intended to provide an account of the impact of man's activities on the natural environment by describing observed changes.

While a considerable amount of knowledge has been accumulated over the last three decades, as reflected in the more than 70 volumes of *The Handbook of Environmental Chemistry,* there are still many scientific and policy challenges ahead due to the complexity and interdisciplinary nature of the field. The series will therefore continue to provide compilations of current knowledge. Contributions are written by leading experts with practical experience in their fields. *The Handbook of Environmental Chemistry* grows with the increases in our scientific understanding, and provides a valuable source not only for scientists but also for environmental managers and decision-makers. Today, the series covers a broad range of environmental topics from a chemical perspective, including methodological advances in environmental analytical chemistry.

In recent years, there has been a growing tendency to include subject matter of societal relevance in the broad view of environmental chemistry. Topics include life cycle analysis, environmental management, sustainable development, and socio-economic, legal and even political problems, among others. While these topics are of great importance for the development and acceptance of *The Handbook of Environmental Chemistry,* the publisher and Editors-in-Chief have decided to keep the handbook essentially a source of information on "hard sciences" with a particular emphasis on chemistry, but also covering biology, geology, hydrology and engineering as applied to environmental sciences.

The volumes of the series are written at an advanced level, addressing the needs of both researchers and graduate students, as well as of people outside the field of "pure" chemistry, including those in industry, business, government, research establishments, and public interest groups. It would be very satisfying to see these volumes used as a basis for graduate courses in environmental chemistry. With its high standards of scientific quality and clarity, *The Handbook of Environmental Chemistry* provides a solid basis from which scientists can share their knowledge on the different aspects of environmental problems, presenting a wide spectrum of viewpoints and approaches.

The Handbook of Environmental Chemistry is available both in print and online via www.springerlink.com/content/110354/. Articles are published online as soon as they have been approved for publication. Authors, Volume Editors and Editors-in-Chief are rewarded by the broad acceptance of *The Handbook of Environmental Chemistry* by the scientific community, from whom suggestions for new topics to the Editors-in-Chief are always very welcome.

Damià Barceló
Andrey G. Kostianoy
Editors-in-Chief

Preface

The Nile River is the main source of water for Egypt, providing more than 97% of the country's water supply. Researchers from all over the world have recently become very interested in the challenges of and cooperation opportunities for the Nile Rive, particularly after the start of the construction of the Grand Renaissance Ethiopian Dam. This volume has been produced to answer many questions and to provide readers, researchers, and scientists with key facts about the Nile in its entirety, covering a variety of topics. This is not an easy task: 34 authors wrote 24 chapters in just over 6 months. Review and editing processes took another 6 months to ensure the highest quality of the technical contents of the book. The volume was sent to Springer, chapter by chapter, to be produced based on the online-first policy. The book is divided into seven parts, each of which comprises several chapters. In the introductory chapter "Nile River Biography and Its Journey from Origin to End," the author presents key facts about the Nile.

Part I of the book consists of four chapters. All of these are about the Aswan High Dam reservoir. In the chapter "Estimating the Life Time Span of Aswan High Dam Reservoir (AHDR) Using Numerical Simulation of Nubia Lake," the authors present the results of a hydrodynamic simulation using the CCHE2D model for Lake Nubia. Then the lifespan of the whole lake is estimated and compared with the cross sections method used by the concerned authority of the AHDR. In the chapter "A Satellite Remote Sensing Approach to Estimate the Life Time Span of Aswan High Dam Reservoir," the authors present a systematic approach to estimate the lifespan of AHDR using a satellite remote-sensing approach and compare the results obtained with those from numerical modeling and the traditional method adopted by the associated authorities of AHDR. The chapter "Estimating the Sediment and Water Capacity in the Aswan High Dam Lake Using Remote Sensing and GIS Techniques" explains the use of a satellite remote sensing approach and GIS technology to estimate the accumulated sediment in Lake Nubia. Then the total sediment in the AHDR is estimated. The results are comparable with estimations using the cross sections method that was adopted by the National Water Research Center, Ministry of Water Resources and Irrigation. The water quality of AHDR is presented and discussed in the chapter "Water Quality Assessment of Aswan High Dam Reservoir." Two water quality indices, the National Sanitation Foundation – Water Quality Index (NSF WQI) and the Canadian Council of Ministers of the Environment (CCME – WQI), and two trophic status indices (Carlson TSI and LAWA TI), are used to assess the southern part of AHDR.

Part II of the book presents results and a review of studies on Nile River morphology and sediment quality and movement from Aswan to the Nile Promontories. The chapter "Morphological Variation of the Nile River First and Second Reaches Using RS/GIS Techniques" presents the results of water surface change detection using satellite images from 1984 to 2010 for the river reaches from Aswan to Esna Barrages (1st reach) and from Esna Barrages to Naga Hammadi Barrages (2nd reach). The chapter "Bed Morphological Changes of the Nile River Downstream Major Barrages" presents the results of 2D numerical modeling to assess the bed morphological changes arising from controlling the release of the flow downstream of the Naga Hammadi Barrages. The author presents a stochastic procedure to deal with the uncertainty emerging from scarcity of available measured data for sediment in the River Nile. The results of analyzing different measurements of natural radioactivity found in the sediments of the Upper Egypt part of the Nile River are presented in the chapter "Distribution of Natural Radioactivity in the Egyptian Part of the Nile River from Aswan to El-Minia" and are compared with those of other authors. The chapter "Assessment of Water Quality and Bed Sediments of the Nile River from Aswan to Assiut, Egypt" presents the results of analyzing the measured physical and chemical parameters for water and sediment for two successive years from February 2011 to August 2012 at ten sites during low and high flow. The authors of the chapter "Morphology of the Nile River due to a Flow Rate over the Maximum Current: Case Study Damietta Branch" present the results of a numerical modeling to study the effect of increasing the flow rate to more than the current maximum on the morphology of the Nile River Dameitta branch. An interesting study on bathymetry detection using satellite remote sensing for Rosetta branch (the second branch of the Nile) is presented in the chapter "Nile River Bathymetry by Satellite Remote Sensing Case Study: Rosetta Branch." The authors provide detailed methodology and assess the performance of remote sensing in detecting the bathymetry in Rosetta branch where the water quality has deteriorated. This part of the volume ends with the chapter "Towards a Dynamic Stability of Coastal Zone at Rosetta Promontory, Egypt." The authors of this chapter discuss the results of using calibrated/validated hydrodynamic and particle tracking models based on the 2D Coastal Modeling System software package (CMS) to test different scenarios to suggest the best scenario to maintain the dynamic stability of Rosetta promontory.

In Part III "Ecosystem, Fish and Fisheries" of the volume, three chapters are presented. The chapter "Ecosystem and Biodiversity in the Nile Basin: Case Study: Lake Nasser" describes aspects of environmental issues of ecosystem and biodiversity, endangered species, and threats to biodiversity in the Nile Basin countries with a focus on Lake Nasser as a case study. In the second chapter "Impact of Water Quality on Ecosystems of Nile River" the author discusses the different pollutants of the River Nile in relation to the biotic and abiotic factors that affect water quality and the aquatic ecosystem as well as the interaction of the human activities on the Nile River water quality. The last chapter of this part is “Fish and Fisheries in the Nile Basin.” It describes the current status of the fish and fisheries of the Nile Basin and suggests several measures to improve the fish industry and to increase the productivity.

Part IV of this volume is “Upper Nile Challenges and Opportunities” and consists of four chapters. In “Trend Analysis of Precipitation Data: A Case Study of Blue Nile Basin, Africa” the author presents an assessment of the availability and quality of remotely sensed and global rainfall data as one of the important forcing collections of data which should be used to set up a hydrological model. The case study of the chapter is the Blue Nile Basin. The chapter “Recent Trends and Fluctuations of Rainfall in the Upper Blue Nile River Basin” presents a trend analysis of annual and seasonal rainfall data collected from 22 stations for 49 years over the upper Blue Nile Basin using non-parametric, Mann–Kendall tests and the Sen’s slope approach. In the chapter “Productivity of Rain-Fed Agriculture of Upper Nile River” the author discusses the rainfed agriculture activities and rainfed production systems in the Nile basin. The last chapter in Part IV is “Impacts of the Upper Nile Mega Projects on the Water Resources of Egypt.” The authors of this chapter explore the impacts of the mega projects (such as the Grand Renaissance Ethiopian Dam) – constructed on both White and Blue Niles – on other water resources of Egypt.

In Part V “Climate Change Variability, Vulnerability and Adaptation” two chapters are presented. The chapter “Nile Basin Climate Changes Impacts and Variability” discusses the climate changes and variability all over the basin and sub-basins. Its structure is around historical climatology and hydrology of Nile basin, variability of the Nile climate, in addition to the impacts of climate change on growth and development. In the chapter “Climate Changes Vulnerability and Adaptive Capacity” the authors discuss the different issues over the basin that are related to vulnerability and adaptive capacity over the Nile Basin. They show how scientific information can be used to prepare for climate changes and different climate model techniques in advance to provide economic opportunities and proactively manage the risks, and consequently how climate change impacts and their associated costs over time are reduced.

In Part VI “The Hydropolitics and Legal Aspects” two chapters are presented. The chapter “The Legal Aspects of the International Rivers: The Nile River as a Case Study” analyzes the legal dimensions of international rivers on the Nile River based on legal analytical methods. In doing so, the chapter covers the regulations of the uses of the international rivers, and consequently the rights of riparian states, the no-harm rule, the principle of equitable and reasonable utilization, and the legal status of the Nile River. The chapter “The Hydropolitics of the Nile River Basin” discusses and analyzes the hydropolitical interactions in the Nile Basin with a focus on conflictual interactions based on the hydropolitical framework. Several issues are analyzed including (1) the dimensions of the water conflict in the Nile Basin, with focus on the contradictory attitudes of the countries upstream and downstream and on the Ethiopian hydropolitical behavior towards the Grand Renaissance Ethiopian Dam, (2) the role of the external factors in regional and international actions in the Nile Basin, and (3) the potential scenarios of the hydropolitics (conflict and cooperation) in the Nile Basin."

Part VII, which contains the last chapter of the volume, presents an update of the recent publications on the topics presented in this volume and ends with the conclusions and recommendations highlighted by the authors.

The project for the production of this book was initiated on June 2015. It took more than 1 year before the first chapter was posted online because of the several review rounds made on the original manuscripts (chapters). Once a chapter manuscript was approved by the editor of the book it was sent to two reviewers, one with English as native language. The author revised the manuscript based on the reviewers' comments and the editor then reread it to check the overall quality of the manuscript. Then the chapter was sent to Springer for production.

I would like to thank all the authors for their contributions – without their efforts there would be no "The Nile River" book. Great appreciation and thanks are due to the editors of the HEC book series at Springer, with special thanks to Prof. Andrey Kostianoy for his continuous support and advices. Words are not sufficient to thank Dr. Sommer Abdel-Fattah, Assistant Professor, McMaster University, Hamilton, Ontario, Canada for her great efforts in reviewing, editing, and improving the quality of all the manuscripts.

Acknowledgements are extended to all members of the Springer team who worked long and hard to produce this volume and make it a reality for graduate students, researchers, and scientists around the world. Last but not least, great thanks and special appreciation to all the authors who contributed to this volume. Without their patience and efforts in writing and revising the different versions, it would not have been possible to produce this volume and make it a reality.

The volume editor would be happy to receive any comments to improve future editions. Comments, feedback, suggestions for improvement, or new chapters can be sent directly to the volume editor.

Zagazig, Egypt Abdelazim M. Negm
March 2017

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Nile River Biography and its Journey from Origin to End

Nader Noureldeen Mohamed

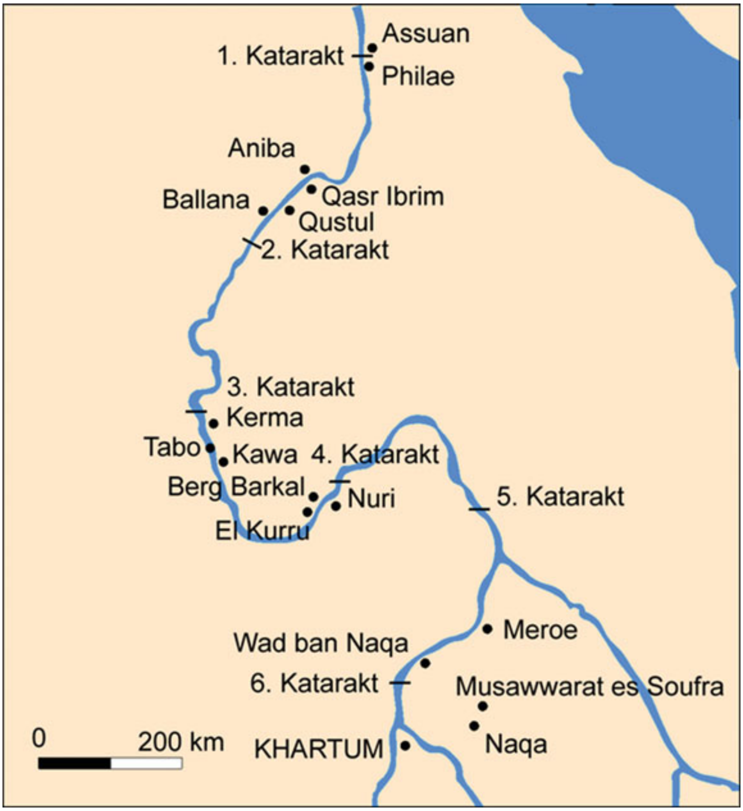
Abstract The Nile Basin covers an area of 3.18 million km^2, nearly 10 % of the African continent, and is shared by 11 countries. The Nile Basin can be divided into two subbasins: The first is the Eastern Nile subbasin or Ethiopian Highland which is considered as the main resource of the Nile water, sharing 85 % of the total Nile water. It is characterized by seasonal steady flow during the summer and autumn months (June–November). The second subbasin is the Great Equatorial lakes which shares only 15 % but with steady flow over the year. From Jinja in Uganda, the White Nile emerges from Lake Victoria and is thusly named the "Victoria Upper Nile." It travels northward toward Lake Kyoga and then through the Victoria Lower Nile to reach the lake of Albert. The river reemerges from Lake Albert as the Albert Nile and journeys northward to the Nimule; the first city in the South Sudan to carry a new name of Bahr el Jebel flows over the Fula rapids, and then the Nile losses and diapers in the biggest swamp in the world "Sudd" (means a "wall or block" in Arabic language) because of the very small gradient in this area. From Lake "No" at the north end of the Sudd swamp, the river turns eastward and at this point is named the "White Nile"; after a short distance, it receives the stream of Sobat River coming for southwest Ethiopia in their east bank and then continues its northward descent to meet with the Blue Nile at Khartoum, Sudan capital. The Blue Nile originates in Lake Tana in Ethiopia; it is joined by a number of tributaries, the main ones being the Rahad and Dinder, both originating in the border of Ethiopia. From Khartoum the combined rivers of the Nile flow northward and are joined by the Atbara (330 km north of Khartoum, originating in northeast Ethiopian Highlands). The Main Nile continues traveling northward and flows into Lake Nasser/Nubia, a major man-made reservoir on the border between Sudan and Egypt that provides interannual regulation for Egypt. The Nile Basin has several lakes such as Victoria,

N.N. Mohamed (✉)
Department of Soil and Water Sciences, Faculty of Agriculture, Cairo University, Giza, Egypt
e-mail: nadernour@hotmail.com

A.M. Negm (ed.), *The Nile River*,
Hdb Env Chem (2017) 56: 1–32, DOI 10.1007/698_2016_107,

Kyoga, Albert, George, Edward, and Tana in addition to six cataracts. Six cataracts and Nine dams are distributed through the river. These dams are: Owen, Kiira, Jebal al-Aulia, Khashm el-Girba, Sinnar, Roseires, Grand Ethiopian Renaissance, Tekeze, and the Aswan High Dam. The cataracts were count from Egypt (1) to Sudan (6).

Dams through the Nile River (the reference below the map)



The Nile Basin is characterized by high climatic diversity and variability, a low percentage of rainfall reaching the main river, and an uneven distribution of its water resources. Climate changes are expected to affect the upper stream Nile by reducing the precipitation by 70 %.

Keywords Climate change, Dams, Lakes, Nile River Basin, Precipitation, Subbasin, Water resources

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1 Introduction

Africa has only about 9 % of global freshwater resources for 15 % of the global population. Africa is the world's second-driest continent, after Australia, with annual per capita water availability of 4,008 m^3 in 2009 which is well below other world regions except Asia, the world's most populous continent [1].

The Nile River is the longest river in the Africa and even in the world, with a total length of 6,695 km, but has a little amount of water (does not exceed 84 BCM a year), making it out of the list of the tenth biggest river water sources in the world [2]. Figure 1 shows the biggest water discharge rivers in the world.

Its basin covers an area of 3.18 million km^2 – some of 10 % of the African continent – and is shared by 11 countries. The Nile River Basin encompasses a broad range of ecosystems that include mountains, tropical forests, high- and low-attitude wetlands, equatorial lakes, woodlands, and savannas. These ecosystems include flora and fauna unique to East Africa. However, most, if not all of these, are threatened by environmental degradation resulting from the region's

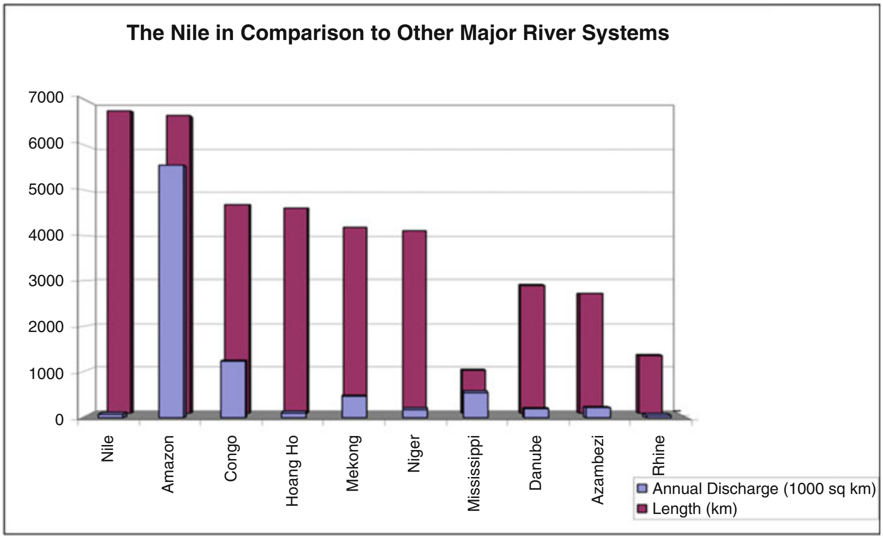

Fig. 1 Nile water in comparison with some well-known international rivers [3]

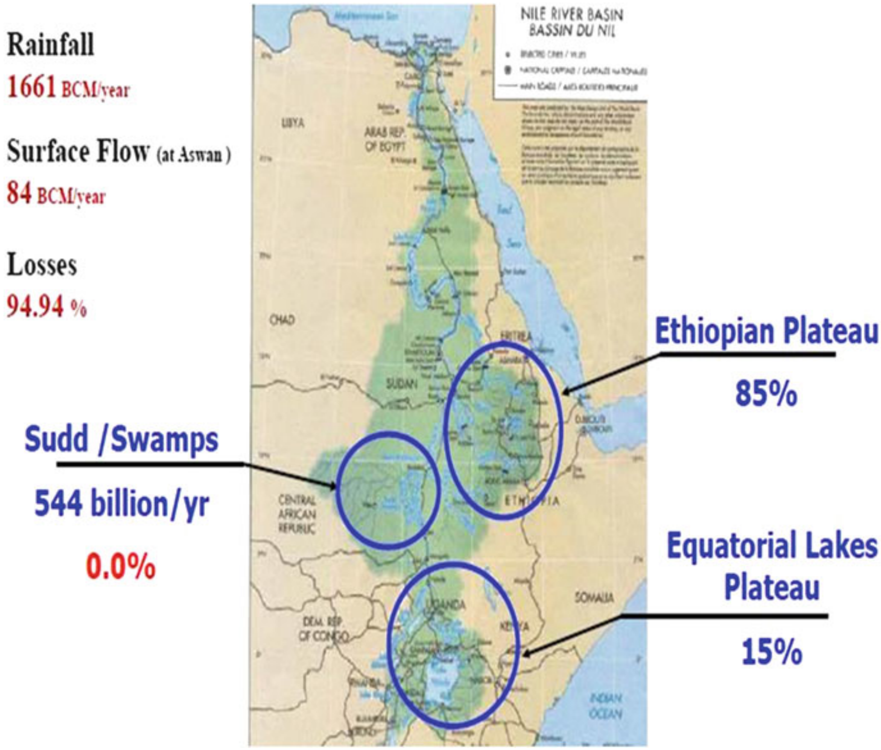

Fig. 2 Water sources in the Nile River [2, 4]

growing population, ongoing development pressure, and woefully inadequate infrastructure. The Nile Basin is characterized by high climatic diversity and variability, a low percentage of rainfall reaching the main river, and an uneven distribution of its water resources. Potential evaporation rates in the Nile region are high, making the basin particularly vulnerable to drought. The Nile Basin is divided into two main subbasins: the first is the Nile equatorial lakes, the source of the White Nile, and the second is the Eastern Nile subbasin, the source of the Blue Nile, Atbara, and Sobat. The White Nile flows only contribute up to 15 % of the annual Nile discharge but are fairly stable throughout the year. The Eastern Nile region supplies up to 85 % of annual Nile flows, but its contribution is highly seasonal [2]. Figures 2 and 3 showed the Nile Basin subbasins and the Nile Basin countries.

Many of the basin's countries are already in a state of water stress or water scarcity, which is defined as less than 1,700 and 1,000 m^3/person/year, respectively, of available freshwater, based on long-term average runoff and pollution. The pressures exerted by the growing population lead to increasing demands for resources leading to loss of forests and wetlands, land degradation, and desertification (Table 1).

Fig. 3 Nile Basin countries and water courses [5, 6]

Table 1 Water discharge of the biggest international rivers [3]

River name	Length	Annual discharge BCM/year	Time of Nile
Nile	6,850	84	–
Amazon	6,700	5,518	66
Yangtze	5,463	525	6.25
Mississippi	5,279	562	6.7
Congo	4,700	1,284	15
Mekong	4,183	264	3.1
Danube	2,888	205	2.5
Niger	2,590	177	2.1

2 Key Facts of the Nile

The basic facts of the Nile River are as follows [1, 2, 4]:

a. Length: 6,695 km
b. Navigable length: 4,149
c. Basin area: 3,176,543 km^2
d. Location: -4S to 31N and 24E to 40E
e. Riparian countries: Burundi, Democratic Republic of the Congo, Egypt, Ethiopia, Eritrea, Kenya, Rwanda, South Sudan, Sudan, Tanzania, and Uganda
f. Mean of annual flow (measured at downstream country, Aswan; Egypt): 84 billion m^3/year
g. The main tributaries and Lakes (from upper to downstream): Victoria Lake – Upper Victoria Nile – Lake Kyoga – Lower Victoria Nile – Albert Lake – Albert Nile – Bahr el Jebal + Sudd Swamp + Bahr el Ghazal and Bahr Arab – Lake "No" – White Nile. Then they meet with Eastern Nile sub-basin: Tana Lake – Baro-Pibor-Sobat, Blue Nile (Abay) + Atbara (Tekeze), Main Nile, and Lake Nasser or the man-made lake of Aswan High Dam
h. Runoff coefficients of main subbasins: 1–16 %
i. Runoff coefficient for the whole basin: 4 %
j. Major lakes in the basin: (equatorial) Victoria, Kyoga, Albert, Edward, George, and (East) Tana
k. Highest point: 5,110 m (Mount Stanley, Rwenzori Mountain, Uganda, and Burundi and Rwanda)
l. Lowest point: −133 m (Qattara Depression, Egypt)
m. Precipitation: mean max, 2,093 mm/year (Gore, Ethiopia); mean min, 0 mm/year (Lake Nasser, Egypt); and mean for the entire basin, 1,046 mm/year
n. Total population of the Nile countries: 437 million (2012)
o. Population within the basin: 238 million (54 % of population of basin countries, 2012)

p. Land use (2009): shrublands and woodlands, 37.3 %; bare soils, 30.8 %; agricultural lands, 11.6 %; grasslands, 10.3 %; forest, 6.9 %; water bodies, 3.0 %; and cities and built-up areas, 0.1 %
q. Main consumptive water use sector: agriculture
r. Population consumed by agriculture: 78 % at the peak flow at Aswan (Egypt)
s. Major dams: Owen Falls two dams (Bugala "Naluaale" and Kiira), Jebel Aulia, Roseires, Sennar, Khashm el-Girba, Merowe, Aswan High Dam, Grand Ethiopian Renaissance Dam, and Tekeze Dam

2.1 Key Problems

The key problems of the Nile River include [4, 7, 8]:

1. High population growth.
2. Drought and dryness.
3. Strong socioeconomic dependency on water.
4. Strong wrong belief on water as a power of wealth.
5. Absence of basin-wide management.
6. Complex hydrology.
7. Environmental hazards.
8. Livelihood issue.
9. Conflict and inequality.
10. Power imbalance and mistrust.
11. Uncertainty and lack of transparency.
12. Weak economic with spread of poverty and hunger.
13. Strong belief in financing water for the upper stream countries and belief in should Egypt pay for water! [7].
14. The Nile Basin countries believe that Nile water is only the water stream running between the two banks of the river, but the rain- or groundwater should not be considered [7].
15. Strong false belief in Egypt is the main reason of their problems, and it should aid the progress and economic development in the upper stream countries [7].
16. Some countries such as Ethiopia are looking forward to be the leadership and the power of East Africa.

3 Geography and Voyage of the Nile River and Its Basins

Worldwide, there are 263 transboundary river basins, which can be defined as basins shared by two or more riparian states. Approximately 60 % of the world's population depends on these international water systems [9, 10]. Transboundary river basins are also important because of the complex natural ecosystems they support. The potential increase in conflicts over shared water resources and the effects of climate change present significant social, economic, and environmental threats. In addition, there is a growing danger to human health from inadequate or unsafe water supplies [10]. Africa's 63 international transboundary river basins cover about 64 % of the continent's land area and contain 93 % of its total surface water resources.

The term "basin" refers to the geographical area drained by a river or lake. The Nile Basin refers not only to the physical drainage area of the Nile with its associated biophysical and ecological elements but also to the people living within the basin and features of their social, cultural, and economic development [9, 10].

Nile Basin can be divided into two subbasins: The first is the Eastern Nile subbasin (Ethiopian Highland) which is considered the main resource of the Nile water and is shared with 85 % of the total Nile water and has seasonal steady flow during the summer and autumn months (June–October). The second subbasin is the Equatorial Nile subbasin (Great Equatorial lakes) and shares only 15 % of the total water but in steady flow over the year or months.

Ethiopia, through the Blue Nile and rivers Atbara and Sobat, contributes about 85 % of the annual natural flow, while the White Nile contributes the balance. The White Nile and the Blue Nile are the two hydrological systems that feed the Main Nile. The former originates in the Equatorial Lakes Plateau (Burundi, Rwanda, the United Republic of Tanzania, Kenya, Democratic Republic of the Congo, and Uganda) and is fed by substantial flow from the Baro-Akobo-Sobat river system that originates in the foothills of southwest Ethiopia.

The Blue Nile stems from Lake Tana in the middle of Ethiopian Highlands. The Tekeze-Setit-Atbara river system stems from the northeast of Ethiopia and contributes to the flow further downstream of Khartoum. The region is also blessed with underground water resources that are already being used to supplement the surface water resources, as shown in Figs. 4 and 5.

The basin extends over five climatic zones – Mediterranean, arid, semiarid, subtropical, and tropical [2, 8, 11]. Its landscapes range from mountains, grasslands, forests and woodlands, wetlands, lakes, and deserts to a wave-dominated delta. This combination results in an array of ecosystems that are home to a rich biodiversity that provide a multitude of benefits to the population through cultural and ecological services, trade, tourism, food, medicines, and other products. The Congo-Nile Divide in Rwanda, the Fayoum lakes in the Egyptian desert, the Sudd wetlands in Sudan, and the Albertine Rift on the border of the DRC with Uganda are some of the areas with a unique or rich biodiversity. There are challenges facing the environment of the region. Population is the main driver behind the ever-increasing demand for water and the chief factor responsible for land degradation and environmental pollution. The pressures exerted by the growing population lead to increasing demands for resources leading to loss of forests and wetlands, degraded lands, desertification, alien invasive species, overfishing, and water pollution [2]. Many of the basin's countries are already in a state of water stress or water scarcity, which is defined as less than 1,700 and 1,000 m^3/person/year, respectively, of available water, based on long-term average runoff:

Fig. 4 The Nile course and its subbasins [1, 11]

Fig. 5 Eastern Nile subbasin [6]

Extensive regional aquifer systems holding substantial quantities of groundwater underlie the Nile region. Some of the aquifers hold fossil water, but others are recharged from precipitation over the Basin, or from irrigation areas and the base flow of the Nile. Groundwater is the dominant source of domestic water supply in rural communities across the Basin. The quality of the Nile waters has generally deteriorated because of population growth, intensification of agriculture, and industrial development. Across the Basin, environmental sanitation is poor, resulting in bacteriological contamination and nutrient enrichment of the Nile waters. While the quality of large parts of the Nile system – in particular in the sparsely populated areas – remains acceptable, localized high pollution is experienced mainly around urban centers. Groundwater in isolated locations also has naturally occurring high levels of dissolved minerals.

3.1 The Course of the Nile

The most distant source of the Nile is the Ruvyironza River, which flows into Lake Victoria through the Ruvubu and Kagera rivers [7]. Other rivers converging into Lake Victoria – the largest of the Nile equatorial lakes – include the Simiyu-Duma, Grumati-Rwana, Mara, Gucha-Migori, Sondu, Yala, Nzoia, Sio, Katonga, and Rusizi. From Jinja in Uganda, the White Nile emerges from Lake Victoria as the Victoria Upper Nile and travels northward, passing through two other equatorial lakes – Kyoga and then through the Victoria Lower Nile to reach the lake of Albert. Through these two lakes, the Nile captures runoff from two mountainous and high-rainfall areas (Mts Rwenzori and Elgon) on the southwestern and southeastern peripheries of the basin.

The river reemerges from Lake Albert as the Albert Nile and journeys northward to Nimule near the South Sudan-Uganda border. From this point, the river, now known as the Bahr el Jebel (meaning river of the mountains), flows over the Fula rapids and through the Sudd before meeting the Bahr el Ghazal (meaning river of the gazelles) at Lake "No." The Bahr el Ghazal drains high-rainfall areas of western South Sudan. From Lake No, the river turns eastward to join with the Sobat River, which carries high, seasonally variable, flows originating in the Ethiopian Highlands. The combined Bahr el Jebel and Sobat rivers form the White Nile, which continues its northward descent and meets with the Blue Nile at Khartoum, Sudan [7].

The Blue Nile (also known as the Abay) originates in Lake Tana in Ethiopia and is the second principal stream of the Nile. Before meeting the White Nile, the Blue Nile is joined by a number of rivers, the main ones being the Rahad and Dinder, both originating in the Ethiopian southwest border with Sudan. From Khartoum, the combined rivers of the Nile flow northward and are joined by the Atbara (Tekeze) (330 km north of Khartoum), also originating in the northeast of Ethiopian Highlands. The Main Nile continues traveling northward and flows into Lake Nasser/Nubia, a major man-made reservoir on the border between Sudan and Egypt that provides interannual regulation for Egypt. The Nile eventually discharges into the Mediterranean Sea via its delta [7].

3.2 Catchment Areas, Dams, and Lakes

The catchments of most of the inflowing rivers have dense rural populations where much of the land is used for subsistence agriculture. Outflow is controlled by the Nalubaale and Kiira dams at Owen Falls, 8 km downstream from the Victoria shoreline. After leaving the lake, the river flows through Lake Kyoga, a shallow wetland complex that is an important fishery for Uganda, and then east to Lake Albert, which also collects inflow from the Semliki River. Flowing north across the Uganda-Sudan border, the river splits into two channels – the Bahr el-Jabal and the Bahr az-Zaraf. Flowing across broad flat plains, the rivers expand into a vast wetland, the Sudd swamp. Covering around 8,000 km^2 during the dry season, the swamp seasonally overflows, flooding an area many times this size [12]. The vast surface area, heavy vegetation, and high temperatures of the Sudd have led to the loss of roughly half the total White Nile's inflow through evaporation and transpiration [13]. The remaining outflow moves north where it meets the Blue Nile, 500 km downstream at Khartoum. The Blue Nile originates at Lake Tana, 1,800 m above sea level in the Ethiopian Highlands, where average annual rainfall is high and evaporation and transpiration are relatively low. It gathers more than 20 tributaries between lakes Tana and Khartoum, including the Rahad, Didessa, Dabus, and Dinder rivers [13]. By the time it reaches the Roseires Dam 80 km into Sudan, it begins to lose more water to evaporation and transpiration than what it receives in rainfall; nevertheless, it has collected enough water to provide between 59 and 64 % of the Nile's flow at Khartoum where it joins the White Nile. Additional inflow from the Ethiopian Highlands comes through the Atbara River, which enters the Nile 300 km downstream. From this point on, the combined effect of large and small irrigation schemes, increased temperatures, and diminishing rainfall cause the river to lose more water than what it receives. In northern Sudan, the Merowe Dam forms an artificial lake that is 174 km long when full [14, 15]. The Nile in Egypt begins with Lake Nasser, a reservoir created by the Aswan High Dam. One of the largest pumps in the world forces water from Lake Nasser into a channel that transports it onto the Western Desert where Egypt has begun a large irrigation and resettlement project. As the Nile flows on from Aswan toward the Mediterranean Sea, it is lined with irrigation canals. Almost all of Egypt's population of 90 million people live along the river and depend heavily on its resources. By the time the river reaches the sea, much of its water has been diverted for irrigation. Along with the water, sediments that have not already been trapped behind the river's many dams are diverted as well. As a consequence, erosion at the delta's margins and subsidence or compaction of the delta's soil is outpacing new deposition, leading the delta to sink and erode [15].

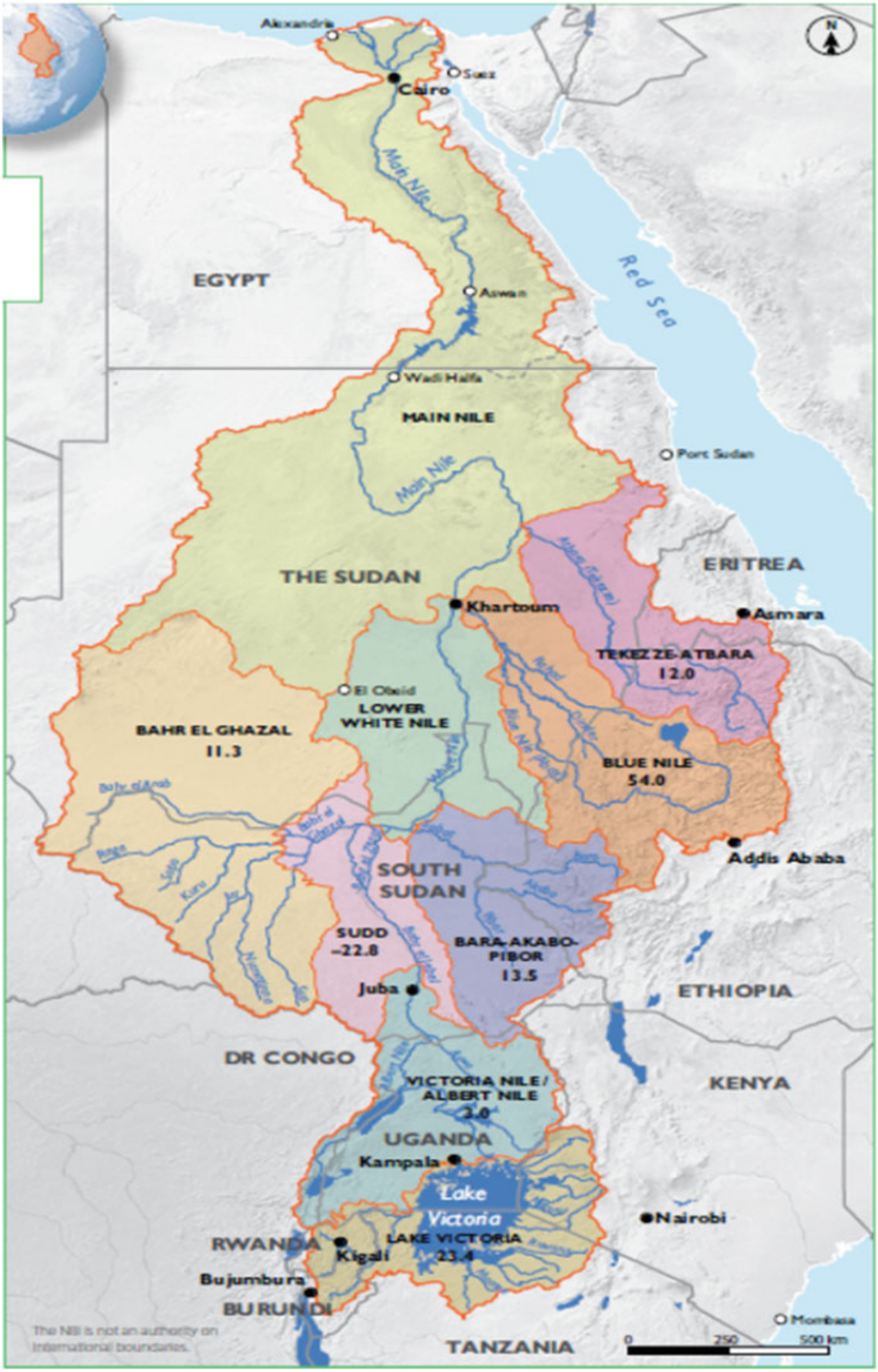

Fig. 6 The main subbasins and their contribution to the Nile (BCM/year) [2]

3.3 The Sudd Swamp and Jonglei Canal

The Sudd is a vast wetland in southern Sudan where the Nile River wanders for nearly 644 km, losing much of its flow to evaporation [16]. During the dry season, the wetlands contract to approximately 8,300 km^2 of permanent swamp [16]. During the wet season from April to October, the Sudd overflows into the surrounding area to cover 80,000 km^2. This annual pattern of flooding is an integral part of the ecosystem and is crucial to the local flora and fauna and to the local Nilotic people's way of life [16, 17].

The Jonglei Canal project is designed to reroute a portion of the Nile's flow around the wetland, thus reducing evaporative loss and increasing the water available downstream for irrigation. The project has been at a standstill since November 1983 when military conflict in the area stopped construction [17]. This conflict has now ended and there are plans to resume construction. According to [18, 19], The Equatorial Nile Project and its Effects on the Anglo-Egyptian Sudan identified many concerns with the Jonglei Canal that are still a source of controversy today. It concluded that a canal diverting 55 million m^3 of the White Nile's water per day would mean the loss of 36 % of pasture and 20,000 metric tons of fish. It would also significantly reduce agricultural production [19]. The pastoralists who depend on the area's seasonal flooding will lose the grasses for their cattle and access to drinking water; in addition, the canals will impede their seasonal migration. Several studies support these concerns, and a little-studied second phase of the project will almost certainly further affect the area. Environmentalists have voiced concern that the project could have drastic effects on the ecosystem, potentially affecting the climate, groundwater recharge, water quality, fisheries, and the local people [18]. The proponents of the canal claim that its benefits will outweigh impacts on the wetlands. In addition to enhancing of downstream irrigation, supporters say that travel from Khartoum to Juba, the main city in the south, will be reduced by 300 km. The impacts of this project are difficult to predict, and further study is needed to ensure that decisions are based on sound up-to-date science (Fig. 6).

4 Climate and Rain

4.1 Rainfall

Annual rainfall distribution over the basin is characterized by highly uneven seasonal and spatial distribution. Most of the basin experiences only one rainy season – typically in the summer months. Only the equatorial zone has two distinct rainy periods. The reliability and volume of precipitation generally decline moving northward, with the arid regions in Egypt and the northern region of Sudan receiving insignificant annual rainfall. The spatial variability of rainfall is clearly illustrated by the pattern of vegetation and distribution of surface water bodies in the basin. Large parts of the Nile watershed do not generate runoff. In fact, the main runoff-producing areas are limited to the Ethiopian Highlands and the Equatorial Lakes Plateau, with some contribution from southwestern Sudan. The relatively small size of the runoff-producing area is central to explaining the very low runoff coefficient of the Nile (3.9 %). Total Nile discharge represents a depth of less than 30 mm if spread over the entire watershed.

4.2 Seasonal Rainfall Distribution [1, 2]

The high temporal variability of rainfall in the basin is demonstrated by the monthly rain records. Broadly speaking, there are three patterns of seasonal rainfall variation:

(1) A single rain peak June–October, with little or no rainfall in other months. Found in subbasins of Eastern Nile and Main Nile.
(2) A fairly evenly distributed rainfall, with a single peak from April to October. Found in northern Uganda and South Sudan. As seen in Fig. 7.
(3) A twin-peaked distribution, peaking in March–May and September–November with considerable but lower rain during other months. This is mostly seen in the Nile Equatorial Lakes Plateau. See histograms from Kijura to Mwanza.

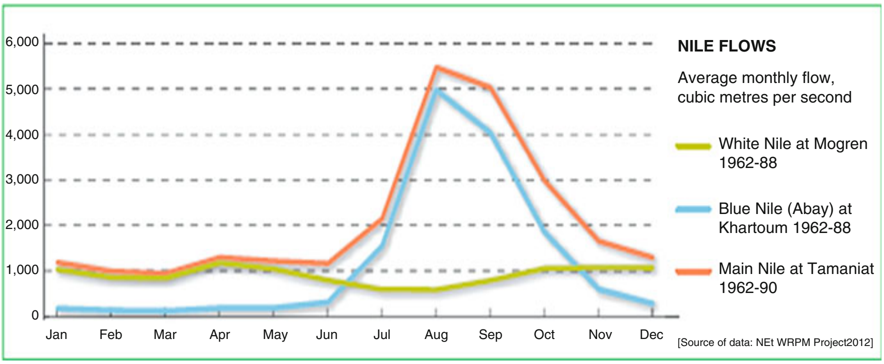

Fig. 7 Nile flow distribution [2]

4.3 Evapotranspiration

4.3.1 Water Loss from the Earth's Surface

Evapotranspiration (ET), which is the sum of evaporation and plant transpiration, is an important element of the water cycle. Evaporation accounts for the movement of water from sources such as soil, canopy interception, and open water bodies to the air, while transpiration accounts for the movement of water within a plant and its subsequent loss to the atmosphere through the plant stomata. Evapotranspiration represents a significant loss of water from drainage basins. Another important term with regard to water loss from the earth's surface is potential evapotranspiration (PET). This is a measure of the amount of water that would be evaporated and transpired if there were sufficient water available. PET is calculated indirectly from other climatic parameters and incorporates the energy available for evaporation as well as the ability of the lower atmosphere to transport evaporated moisture away from the land surface. Actual evapotranspiration (ET) is said to equal potential evapotranspiration (PET) when there is ample water. Actual evapotranspiration in the Nile Basin is generally high compared to other river/lake basins around the world.

4.3.2 Spatial and Temporal Evapotranspiration Trends

Potential evapotranspiration varies considerably across geographical regions and over time. PET is higher in locations and during periods when there are higher levels of solar radiation and higher temperatures (and hence where there is greater energy for evaporation). Accordingly, PET is higher in hot deserts, low-lying lands, and areas near the equator. PET is also higher on less cloudy days and during the dry season (or summer). PET is higher on windy days because evaporated moisture can be quickly transported away from the ground or plant surface, allowing more evaporation to fill its place. Potential evapotranspiration further depends on relative humidity, the surface type (such as open water), percentage soil cover, the soil type (for bare land), and the vegetation type. Across the Nile region, actual and potential evapotranspiration vary markedly. The arid lands in Sudan and Egypt have higher potential evapotranspiration rates than the humid headwater regions of the Nile. However, both have much lower actual evapotranspiration rates because there is little available water and vegetation to cause evapotranspiration. Total annual evapotranspiration is highest in the Lake Victoria subbasin, estimated at about 307 BCM, followed by the Blue Nile subbasin, estimated at 264 BCM and then by the Sudd subbasin estimated at 260 BCM. The Main Nile subbasin downstream of Khartoum has the lowest evapotranspiration rates, estimated at 7 BCM per year. In terms of components of evapotranspiration, the Blue Nile (Abay) subbasin has the highest ET losses over land; Lake Victoria subbasin has the highest evaporation losses over open water; and the Sudd subbasin has the highest ET losses over wetlands. Seasonal/monthly variability of evapotranspiration is a function of temperature, wind speed, relative humidity, solar radiation, and biomass production. No significant month-to-month or year-to-year variation is noted in the upper reaches of the Nile as the areas lie in the tropics that are characterized by all-year sunshine and humid conditions.

4.3.3 A Diverse and Highly Variable Climate

The within-year and between-years variability in rainfall over the Nile Basin is high, making overreliance on rainfed supply or production systems risky. The high potential evaporation values in the Nile region – ranging from some 3,000 mm/year in northern Sudan to 1,400 mm/year in the Ethiopian Highlands and around 1,100 mm/year in the hills in Rwanda and Burundi – make the basin particularly vulnerable to drought events. Drought risks are further amplified by the high variability of the rainfall between seasons and years. This is manifested by uncertainty in the onset of rains, occasional cessation of rainfall during the growing season, and consecutive years of below-average rainfall. This has a marked adverse impact on the productivity of rainfed agriculture and represents a serious constraint to rural development. The impact of the climatic variability on agricultural production is further aggravated by widespread soil degradation that has led to a reduction in the capacity of soils to hold moisture. Rain deficits, therefore, quickly translate into crop failure.

5 Lakes of the Nile Basin

5.1 Great Equatorial Lakes Nile [20–22]

5.1.1 Lake Victoria [14]

Lake Victoria, the second largest freshwater body in the world (area 68,800 km^2), is generally shallow with a maximum depth of 80–90 m and an average depth of 40 m and has a volume of 2,760 lm^3. It is shared by Kenya, Uganda, and Tanzania; Kenya has the smallest portion of the lake by 6 %, Uganda has 45 %, and Tanzania has the largest portion by 49 %. The Lake Victoria basin has an area of 210,000 km^2, with the largest areas in Tanzania by 44 %, Kenya 21.5 %, Uganda 15.9 %, Rwanda 11.4 %, and Burundi 7.2 %.

Lake Victoria has an irregular shoreline of about 3,440 km in length. Its catchments are constituted by five countries (Kenya, Tanzania, Uganda, Burundi, and Rwanda) and drained by a number of large rivers plus many small rivers and streams. The Nile River is the single outlet and 82 % of the water input in the lake comes directly from rainfall.

Kagera River is the largest and longest contributor water in the equatorial lake sub-basin. It originates from Burundi and forms the border between each of; Rwanda-Tanzania and Tanzania-Uganda. The satellite images of 1987 and 2008 show high reflectance of water from the Kagera River due to silt. Silt and suspended solids impact water bodies by loading nutrients into the lake. Nutrients stimulate algae growth which reduces oxygen leading to oxygen depletion that can cause fish kills.

5.1.2 Lake Kyoga

Lake Kyoga occupies a shallow dendritic valley system, part of which is permanently flooded to form a series of shallow lakes, which have a combined maximum open water surface of 341,600 ha and 218,400 ha of permanent swamps. The system is a tributary to the Victoria Nile which flows through the southwestern end of Lake Kyoga and then receives the discharge of Lake Kwania 32 km downstream. The system owes its existence to the upwarping of the western edge of the Lake Victoria basin, which has reduced the gradient and rate of flow in rivers flowing west, causing “ponding” and turning them into sluggish swampy tracts. Lake Kyoga (1°13′-1°47′N/32°33′-33°29′E) is the largest lake in the system. At high water, its surface is 1,034 m asl and covers 263,600 ha. The maximum depth is then 10.7 m and the mean depth about 3 m; the surface level fluctuates by as much as 3.8 m during a year. The lake discharges at the western end into the Victoria Nile and is oriented roughly E-W for 55 km immediately above the confluence, at which point it divides into two arms. The northeastern arm continues up the valley of the Omunyal River for a further 55 km, while the southeastern arm extends up the valley of the Mpologoma River for some 34 km. Many tributaries enter the Omunyal arm, the valley of which contains only minor swamps. By contrast, a vast permanent swamp extends up the Mpologoma arm for 102 km above the lakehead, including many minor lakes, the largest of which are lakes Adois (1°20′-1°25′N/33°30′-33°37′E), Kiando (1°23′N/33°24′E), Naragaga (1°23′N/33°27′E), Nyaguo (1°20′-1°22′N/33°41′-33°45′E), Nyasala (1°17′-1°22′N/33°34′-33°40′E), Namasajerl (1°21′N/33°22′E), Nakuwa (1°05′-1°17′N/33°24′-33°30′E), Nawampasa (1°16′N/33′22′E), Kawi (1°12′N/33°37′E), and Lemwa (1°07′N/33°41′E). The swamp belt reaches widths of 20 km and extends up several side valleys, covering more than 106,000 ha if the very variable lake surfaces are included. The maximum recorded depth is 5.4 m at high water and mean depth is estimated as 4 m. There are several small swamps around the lake margin.

5.1.3 Lake Albert and Semliki River

Lake Albert lies between two parallel escarpments in the Western Rift Valley, at an altitude of 619 m, with an extreme length of 180 km and a maximum width of

43 km. Just over 56 % of its surface is in Uganda and the rest in the Democratic Republic of the Congo (DRC). Its deepest point, 56 m, lies 7 km off the western shore, from where the land rises steeply to a high plateau more than 2,000 m asl. The lake floor slopes gently upward toward the east, but the eastern escarpment rises abruptly just a few kilometers from the east bank in Uganda. The lake is subject to violent windstorms which cause the upwelling of bottom waters, but even without these happenings, the lake is generally well mixed. During calm periods, which frequently occur between November and February, a degree of stratification are develops, and dissolved oxygen levels falls down, but not deleteriously for the fauna.

Semliki River is one of the most important rivers that forms Uganda's natural drainage system found in Bundibugyo District, in the Western Uganda. The river derives its origin from Lake Edward through Mt. Rwenzori and also through a series of tributaries that join along its 140 km course in the Albertine Rift (Western Rift Valley) before draining into Lake Albert. Over 10 m of the riverbank on Uganda's territory is eroded annually at various points of the river, and as a result, the river seems to have doubled its width within the last ten years. Increased riverbank erosion due to overgrazing, melting of ice on the Mount Rwenzori, and degradation of the water catchments has resulted in siltation, changing the river course significantly over the years as it enters the Lake Albert. The bathymetry of Lake Albert shows that the lake is shallower in the south where the Semliki River drains into the lake.

5.1.4 Lake George

Lake George, which straddles the equator, is situated on the floor of the Western Rift Valley. It has a maximum E-W length of 30 km, a N-S width of 16 km, a maximum depth of 7 m, and a mean depth of 2.4 m. It is fed by several rivers and drains from the southwestern end by the Kazinga Channel which leads to Lake Edward. This is 36 km long with a mean width of about 1 km. The principal affluent streams (Nyamwamba, Rukoki, Mubuku, Ruimi rivers) drain the eastern slopes of the Rwenzori Mountains and enter the lake through extensive swamps (0°03′–0°16′/%1130°09′–30°19′E) on the north shore. These swamps are 21 km long, up to 14 km deep, and occupy some 2,600 ha. The Mpanga also enters these swamps from the eastern edge of the rift valley escarpment, while two other affluents enter on the southern shore, from the Virunga Massif, and the westward flowing section of the Katonga River enters the eastern extremity of the lake. Other swamps are situated north and south of the small western basin of the lake, and another is situated on the central southern lakeshore. There are three large islands close to the western shore, one of which almost blocks the channel connecting the main basin with a smaller basin in the northwest.

The Lake George area has seen much volcanic activity over the past 12,000 years, and a small crater lake is connected to the main lake by a narrow channel just south of the beginning of the Kazinga Channel. There are four isolated crater lakes north of the Kazinga Channel and a dozen south of it.

5.1.5 Lake Edward

Lake Edward is 76 km long with a maximum width of 39 km. Just over 29 % of its surface is situated in Uganda. It is connected to Lake George, effectively a bay of Lake Edward, by the Kazinga Channel, 36 km long and about 1.5 km wide. Lake Edward reaches a maximum depth of 112 m, just 5 km from the western shore, above which the land rises precipitously to a high plateau, over 2,000 m asl, carrying mountain peaks over 3,000 m. By contrast the lake floor slopes up gradually to the Ugandan shore. There are extensive swamps at the mouths of the Ishasha and Chiruruma rivers covering about 14,000 ha (Fig. 8).

Fig. 8 The Great Equatorial lakes Nile subbasin [1]

5.2 *Eastern Nile Subbasin Lakes*

5.2.1 Lake Tana

Lake Tana, found in the Amhara region in the northwestern Ethiopian Highlands, is the largest freshwater lake in Ethiopia. It is situated in a wide depression and has a surface area ranging between 3,000 and 3,600 km^2 depending on the season. It is about 84 km in length and 66 km wide, with a maximum depth of 14 m and an elevation of 1,788 m. Lake Tana is fed by four main rivers, the Gilgel Abay, Ribb, Gumara, and Magech, and discharges at Bahir Dar through the Blue Nile. The four inflowing rivers contribute 93 % of the lake's inflow. The average flow from Lake Tana was estimated at 3.8 BCM/year swelling to 54 BCM by the time it reaches Khartoum as a result of contributions from the rivers Dinder and Rahad. A water regulation weir constructed in 1996 at the point where the lake discharges into the Blue Nile helps to control the lake levels for the downstream hydropower plant. The mean annual rainfall is estimated at 1,248 mm/year, while the mean annual evaporation is approximated at 1,690 mm/year [14, 23–25]. The flow of the Blue Nile can be described as torrential; it also carries a very heavy load of silt. Figure 9 shows Lake Tana and its water catchment areas.

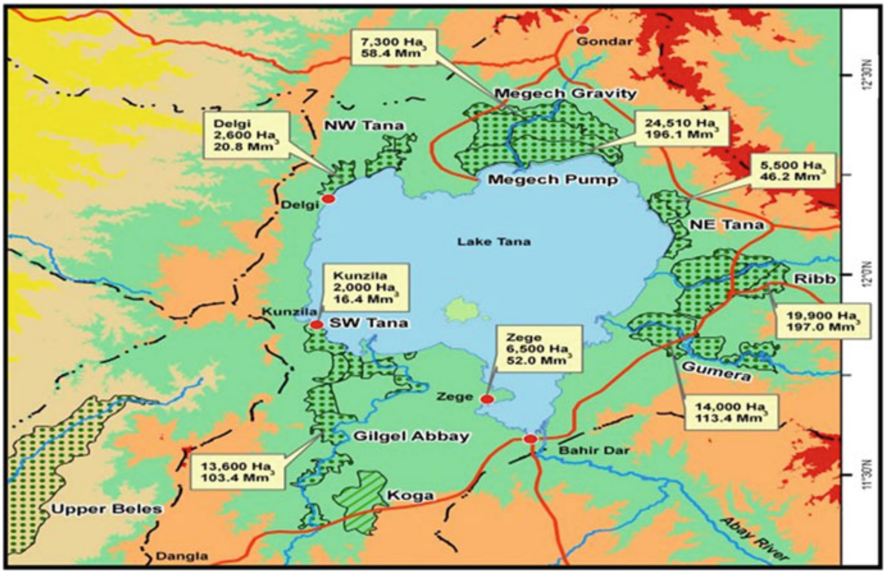

Fig. 9 Lake Tana Eastern Nile subbasin [25]

Wetlands

Wetlands cover about 100,000 km^2 or 3 % of the Nile Basin area [2]. They include swamps, marshes, seasonally inundated grasslands, swamp forests, floodplains, and riparian wetlands (at the edges of lakes and rivers). These wetlands have critical ecosystem functions: they provide a buffer protecting against the impacts of the strong seasonal variations in rainfall patterns, store floodwaters, and help to maintain river flows even during dry spells. They also trap sediments and purify agricultural, industrial, and urban wastewater, and they can influence local microclimates especially when very large as in the case of the Sudd. Wetlands are among the most biologically productive ecosystems, and because of this they are under great pressure.

The Sudd and Machar Swamp in South Sudan

Once in South Sudan, the White Nile breaks up to form the Bahr el-Jabal and Bahr az-Zaraf rivers. These rivers spread over a broad flat plain and expand into a vast wetland – the Sudd swamp. The Sudd in South Sudan is the largest wetland in Africa covering a dry season area of 8,000 km^2 and between 30,000 and 40,000 km^2 during the wet season [1, 21]. It includes the Bahr el Ghazal swamps and the Machar Marshes as shown in Fig. 10. The Bahr el Ghazal basin has the highest rainfall in South Sudan, most of which is absorbed by the swamps, and as such there is hardly any runoff to the White Nile. In fact, it is estimated that the outflow from the Sudd is only about 50 % the inflow due to losses to evapotranspiration [14, 24, 25].

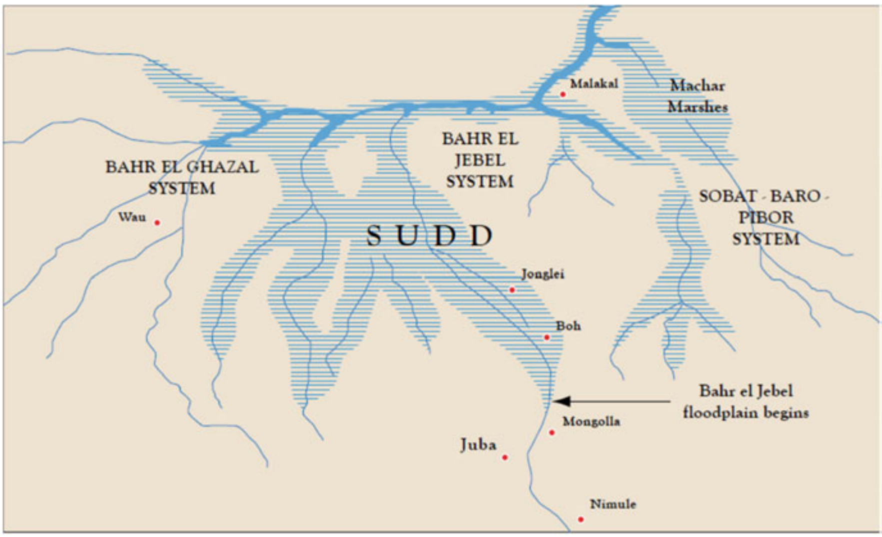

Fig. 10 Swamps area in South Sudan [1]

Despite this, outflows from the Sudd are fairly constant with little seasonal variation. According to [23], the total discharge from the Sudd to the White Nile at Malakal approaches 15.5 BCM per year.

Mara Wetland

The Mara wetland is a riverine floodplain situated near the discharge mouth of the River Mara to Lake Victoria in Tanzania part. In the upstream river catchment, there are numerous economic activities and significant land-use changes. There are also changes occurring in the rivers' hydrological regime with impacts on water quality and the ecological status of both Lake Victoria and the Mara wetlands.

The Ethiopian Wetlands

Ethiopia has many wetland ecosystems. These include alpine, riverine, lacustrine, and floodplain wetlands, and they are found in both the highlands and lowlands. They occur most commonly in the northwestern and western highlands, the rift valley, and the eastern highlands [26].

Wetlands in Rwanda

Rwanda has seven types of swamps, classified on the basis of relief, altitude, soil type, vegetation type, slope of the watershed, population density, hydrology, and size of the swamp [27]. They are mainly seasonal with floodplains of less than 200 m overall. Rugezi and Kamiranzovu are high-altitude wetlands, while most of the others are low altitude. Four wetlands have been classified as critical: Kamiranzovu wetland in Western province, Rweru-Mugesera wetland in Eastern province, Rugezi-Ruhondo wetland shared by Musanze and Gicumbi in Northern provinces, and Akagera wetland shared by Kibungo and Umutara in Eastern province.

Dams of Different Kinds, Financed in Different Ways

Dams come in many shapes and sizes and have many different purposes. Some 52,000 large dams have been built over the last century. These have been funded by governments, private banks, donor agencies, and private investors and built under a hundred or more different national and international regulatory systems that have evolved over the years. Dams may be multipurpose projects that combine several functions. Larger-scale dams offer the potential for hydropower, irrigation, water supply, navigation, and flood management projects [26]. There are many different types of hydropower at different scales, ranging from isolated household supplies to small, mini-, and microscale hydropower for decentralized grids to large grid-feeding projects serving national or regional power markets.

While the main bodies of national and international standards for environmental and social performance are broadly applicable to all types of dams, hydropower dams present unique considerations, not only in terms of financing sources but also in terms of low-carbon energy strategies. There are also much better data sets for planned hydropower plants due to intense private- and public-sector activity in this market. Data for planned flood control or irrigation dams are much harder to find and collate, and these tend to be purely public-sector projects.

Through its focus on hydropower, this review necessarily touches on the relationship between hydropower and other intermittent renewable energy sources for grid-scale power. Large hydropower dams may serve to complement solar and wind power sources as part of a low-carbon energy supply mix. Run-of-river hydropower projects may fit into low-carbon energy systems in developing countries.

Large dams are expensive infrastructure projects that are built within a complex legal and financial regulatory landscape. Social and environmental measures can be expensive, in some cases reaching up to 40 % of project cost or more. For private investors significant costs in these areas affect the profitability (and therefore viability) of the project. While some developers may have internal corporate social responsibility guidance that provides a framework for addressing these issues, the majority decide their environmental and social measures based on the legal requirements stemming from national legislation, usually through environmental assessments. If international financing is involved, however, then donors or private banks may impose additional conditions.

Hydropower has specific impacts that are significantly different from other infrastructure projects such as roads or airports and often have far-reaching effects on resources. Water is used by many communities, both upstream and downstream, and river valleys have traditionally been the focus of settlement and agricultural activity. Large dams have impacts on ecosystems, communities, and other water users (cities, agriculture, fisheries) many miles downstream, and the range of additional safeguards, processes, and policies addressed in this review have been developed specifically to address them.

The major reservoirs on the Nile River Basin – the Roseires, Sennar, and Khashm El-Girba in Sudan and the Aswan High Dam in Egypt – are important for irrigation purposes. In the delta, there are four main barrages: the Delta barrage (actually consisting of two separate dams), the Zifta barrage and Farascour Dam in the Damietta, and the Edfina barrage in the Rosetta. A barrage is an artificial barrier used to increase depth or sustain a separation between fresh- and saltwater. Figure 11 shows the location of some of these dams on the Nile.

The Aswan High Dam and Lake Nasser, Egypt

Located in the lower Nile River Basin, Lake Nasser is situated on the border between Egypt and northern Sudan. The lake was created following the

Fig. 11 Dams along the Nile River [2]

construction of the Aswan High Dam in 1963 to provide a multipurpose storage reservoir for water supply, hydropower, irrigation, and improved navigation. This artificial lake extends from southern Egypt to northern Sudan and has a surface area of 5,248 km^2 and a total volume capacity of 162.3 km^3 [28–30]. This capacity varies depending on the extent of the annual flood upstream. Although approximately 84 BCM flows each year to Lake Nasser in Egypt, heavy use of the lake's waters means that only about 0.4 BCM actually reaches the Mediterranean Sea [29]. It is situated in a hot, dry area, and therefore annual losses to evaporation can be quite high – ranging from up to 10 % when full to about 3 % when at minimum capacity [31].

The Aswan High Dam has had a large impact on the river's flow regime downstream of the dam. This reservoir fully controls the Nile's water flows by eliminating the normally high flows during August and September and limiting maximum discharges to 270 MCM/day or less than one-third of the earlier peak values [29]. One side effect has been a gross reduction in the deposition of the silt that used to annually renew the fertility of Egypt's agricultural lands.

Tekeze Dam and Renaissance Reservoir in Ethiopia

The River Tekeze in northern Ethiopia is a tributary of the Atbara River, which joins the main course of the Nile 300 km north of Khartoum. The Tekeze Dam was completed in early 2009 primarily to produce hydropower and is expected to produce 300 MW of hydropower when fully operational. There are concerns about the dam's environmental impacts. In 2008, a large landslide necessitated the addition of massive retaining walls to keep the slopes from eroding [10].

In the spring of 2012, work began on Ethiopia's Grand Renaissance Dam, also called the Millennium Dam, which has become the key project in the nation's plan to increase its electricity supply fivefold by 2015. It will have a capacity of about 6,000 MW and a reservoir capacity (74.5 BCM) two times that of Lake Tana. The dam will span a part of the Blue Nile in the region of "Benishangul-Gumuz," and when finished, it will be Africa's largest hydroelectric power plant. There are also plans to build four additional dams on the Blue Nile.

Grand Ethiopian Renaissance Dam (GERD), situated on the Blue Nile River immediately upstream of Sudanese border, is a cornerstone piece of this plan as seen in Fig. 12. Upon completion it will be the largest hydropower producer in all of Africa (National Geographic Daily News), with a catchment area of nearly 200,000 km^2 [32, 33], accelerating Ethiopia's transition into a power generation hub. Construction of the hydropower project started in mid-2011 and is scheduled to be fully operational by 2017. The GERD is not only unique for its 6,000 MW of potential [30, 34], more than twice the existing potential in Ethiopia, but for the substantial hydrologic implications it poses for downstream countries. The policies adopted for filling and managing the massive reservoir, with a total storage volume of 74,500 billion cubic meters (BCM), will directly impact the millions of people in downstream countries who rely on the Blue Nile's waters. Implications of climate

Fig. 12 The location of the Grand Ethiopian Renaissance Dam GERD (Google map)

Fig. 13 The location of GERD and the expected Blue River dams [35]

variability and emerging climate change within Ethiopia cast further uncertainty on potential filling policies and system operations.

Ethiopia also plans to build another four dams in the Blue Nile because of the huge amount of silt effluent which reached 136.5 million tons a year, and that need some trap dams to catch some of this silt behind the suggested four dams (Fig. 13).

The Sinnar, Jebel Aulia, and Khashm El-Girba Dams in Sudan

According to the World Commission on Dams (WCD 2000), the Sinnar Dam is the oldest in Sudan. It was built on the Blue Nile some 300 km south of Khartoum in 1926 to irrigate the Gezira Scheme, one of the world's largest irrigation projects. It is thus crucial to Sudan's economy. About 50 km southwest of Khartoum is the Jebel Aulia Dam, which was built in 1937 to support the Aswan Dam in southern Egypt. It was only in 1977 that Sudan gained control of the Jebel Aulia Dam.

The lake formed by the dam has a thriving fish population from which about 15,000 tons of fish is harvested annually.

The Khashm El-Girba Dam on the Atbara River some 200 km downstream of the Ethiopian border was built in 1964 to irrigate the Khashm El-Girba Agricultural Scheme and later the New Halfa Scheme. Later on, it began to produce hydropower. The reservoir lost 50 % of its capacity within 40 years due to siltation, with that proportion rising to 60 % over time. This concurrently impacted the amount of water available for irrigation and also affected hydropower production, which is now limited to only the flood season. The reservoir is flushed occasionally to remove sediment [33].

Roseires and Merowe Reservoirs in Sudan

The Roseires Dam on the Blue Nile was built for flood retention, irrigation, and hydropower purposes. Since its commissioning in 1966, the reservoir's capacity has declined by about 30 % due to sedimentation. It now generates a fraction of the potential hydropower available during the rainy season because the turbine intakes are frequently blocked by sediment. Dredging to remove sediment is conducted frequently [34]. Merowe multipurpose dam, one of Africa's largest hydroelectric projects, was completed in 2009. It is located in north-central Sudan near the Nile's fourth cataract. It was designed to generate about 6,000 GWh of electricity per year and to irrigate approximately 400,000 ha of crops. However, despite the expected economic benefits, there have also been some negative social, environmental, and archaeological costs, including significant loss of land for agriculture and human settlement.

Owen Falls Dam in Uganda

The Owen Falls Dam, now known as the Nalubaale Dam, is located near Jinja in Uganda. It was built in 1954 to generate hydroelectricity for Uganda and Kenya. The dam controls the upstream discharge from Lake Victoria and was Uganda's largest power station. In 1999, the Kiira Power Station extension was built about 1 km from Nalubaale, which allowed more water to be released and increased the hydropower capacity. This fact, along with a protracted drought in 2003, is thought to have contributed to the lowering of the lake to an unsustainable level [32, 33, 36] (Fig. 14).

Fig. 14 Nalubaale and Kiira dams in Uganda (Google Earth 2009)

References

1. African Water Atlas (2010) United Nation Environment Programme. ISBN:978-92-807-3110-1
2. The State of the Nile river basin (2012) The Nile Basin Initiative (NBI), October 2012. ISBN:978-9970-444-00-7
3. International Rivers; people, water. Life. https://www.internationalrivers.org/
4. NBI (2012) NBI role in facing energy security challenges in the Nile basin, Mekong 2 Rio+20 Int'l Conference, On transboundary river basin management, Phuket, Thailand (1–3) May 2012
5. Institute for Technology and Resources Management in the Tropic and Subtropics (2014) The Nile basin summary of basin characteristics handout. Sustainability of engineered river in arid lands: 13–16 Jan 2015

6. World Water Council (WWC) (2000) World Water Vision Commission Report: a water secure world
7. UNDP (2013) Adaptation to climate changes induced water stress in the Nile basin. A vulnerability assessment report. United Nation Environmental Programme. ISBN:978-92-807-3328-0
8. Noureldeen N (2014) Egypt and Nile basin countries: life, water, dams and the conflict (in Arabic language). Publisher Dar Nhdet Misr. ISBN:978-977-14-5173-0
9. World Water Council (WWC) (2011) Sixth world water forum. http://www.worldwaterforum6.org
10. UNU (2006) International rivers and lake basin management, United Nations University. http://www.unu.edu/env/water/transboundary-water.html
11. Karyabwite DR (2000) Water sharing in the Nile river valley. United Nations Environment Programme (UNEP). UNEP/DEWA/GRID, Geneva
12. FAO (2011) FAO-Nile synthesis report. Information products for Nile basin water resources management. FAO-Nile Basin Project GCP/INT/945/ITA 2004 to 2009. Food and agricultural organization (FAO) of the United Nations, Rome. http://www.fao.org/nr/water/faonile/products/Docs/Reports/Synthesis.pdf
13. Ahmad AM (2008) Post-Jonglei planning in southern Sudan: combining environment with development. Environ Urban. 20:575–586. Sage publications on behalf of International Institute for Environment and Development (IIED). http://eau.sagepub.com/content/20/2/575.full.pdf+html
14. Sutcliffe JV, Petersen G (2007) Lake Victoria: derivation of a corrected natural water level series. Hydrol Sci J 52:1316–1321
15. Hildyard N (2008) Bystanders and human rights abuses: the case of Merowe Dam. Sudan Studies 37, April 2008, published by Sudan Studies Society of the United Kingdom
16. Howell P, Lock M, Cobb S (1988) Jonglei Canal: impact and opportunity. Cambridge University Press, Cambridge
17. Bohannon J (2010) The Nile Delta's sinking future, climate change and damming the Nile threaten Egypts's agricultural Oasis. Science 327:1444–1447
18. Krishnamurthy V (1980) The impact foreseen of the Jonglei Canal scheme on the fisheries on the Sudd region: The problems and solutions. In CIFA technical paper No. 8: Seminar on river basin management and development, Blantyre, Malawi, 8–10 December
19. Laki S (1994) The impact of the Jonglei Canal on the economy of the local people. Int J Sust Dev World 1:89–96
20. Uganda Nile Discourse Forum January (2013) Baseline survey on lakes Edward and Albert integrated fisheries and water resources management project
21. Uganda (2011) Ministry of water and energy publication
22. National Environment Management Authority (Nema) and Uganda Atlas of Our Changing Environment Publisher (2013) Highlights of the Uganda Atlas of our changing environment pollution of water bodies
23. Fahmy A (2006) The identification of hydrological units in the Nile basin. Data availability. FRIEND/Nile (FN) UNESCO Flanders science. Trust fund project. The United Nations Education, Scientific and Culture Organization (UNESCO), Paris
24. ILEC (1999) World lakes database. International Lake Environment Committee foundation (ILEC), Shiga, Japan. http://www.ilec.or.jp
25. Wale A (2008). Hydrological balance of lake Tana. Upper Blue Nile Basin, Ethiopia. MSc. Thesis. ITC, the Netherlands. http://www.itc.nl/library/papers_2008/msc/wrem/wale.pdf. Accessed 3 May 2013
26. Abebe YD, Geheb K (2003) Wetlands of Ethiopia. Proceedings of a seminar on the resources and status of Ethiopia's wetlands. vi + 116pp. The World Conservation Union (IUCN), Nairobi
27. REMA (2009) State of the environment and outlook report. Rwanda Environment Management Authority (REMA), Kigali

28. Elsawwaf M, Willems P (2012) Analysis of the climate variability on Lake Nasser evaporation based on the Bowen ratio energy budget method. J Environ Biol 33:475–485. https://lirias.kuleuven.be/bitstream/123456789/324662/2/Mohamed+(JEB+2012).pdf
29. Mutua F, Baldassare GD, Elshamy M, Soliman E, Kigobe M, Ndomba P, Mutemi J, Moge S, Xuan Y (2011) Future hydrology and climate in the river Nile basin. Hydrolog Sci J 56 (2):199–211
30. Sutcliffe J, Parks YP (1999) The hydrology of the Nile. IAHS Special Publication No. 5. International Association of Hydrological Science (IAHS), Oxfordshire, UK
31. UNEP (2013) Adaptation to climate-change induced water stress in the Nile Basin: A vulnerability assessment report, Division of Early Warning and Assessment (DEWA). United Nations Environment Programme (UNEP). Nairobi, Kenya
32. Belachew CT (2013) Benefit of Grand Ethiopian Renaissance Dam Project (GERDP) for Sudan and Egypt. EIPSA Communicating Article: Energy, Water, Environment & Economic 1(1):1–12
33. Siyam AM (2005) Assessment of the current state of the Nile basin reservoir sedimentation problems. The Nile Basin Capacity Building Network (NBCBN). River Morphology research cluster group 1
34. Geomechanical characterization of residual soils for foundation design of a bituminous faced rock fill dams. http://www.pietrangeli.com/assets/uploads/pubblicazioni/file/536a03ce9a1f3.pdf
35. Personal communication with the Saleny company which designed the dam
36. USDA (2005) Low water levels observed on Lake Victoria. Production estimates and crop assessment division foreign agricultural service. http://www.fas.usda.gov/pecad/highlights/2005/09/uganda_26sep2005/index.htm

Part I
The Aswan High Dam Reservoir

Estimating the Life Time Span of Aswan High Dam Reservoir Using Numerical Simulation of Nubia Lake

Abdelazim M. Negm, Tarek Abdel-Aziz, Mohamed Nassar, and Ismail Fathy

Abstract It is expected that the Grand Ethiopian Renaissance Dam (GERD) will be completed and put into operation within few years. The pattern of sedimentation will be affected as well as the amount of sediment accumulation in the Aswan High Dam Reservoir (AHDR). Also, the life time span of AHDR will be greatly affected. In this chapter, a two-dimensional numerical model CCHE2D is applied to study the scouring and silting processes in AHDR from km 500 to km 350 upstream Aswan High Dam (AHD). The sediment transport is simulated in terms of the depth-averaged sediment concentration. The different cross sections along Nubia Lake (Sudanese part of the reservoir) are predicted for the year 2010 and the year 2020. Statistical indicators showed that the model results are accurate enough to be used to predict the morphological changes and the life time span of AHDR. The results show that the life time span of dead zone (LTSDZ) is 254 years, while life time span of life zone (LTSLZ) is 964 years.

Keywords Aswan High Dam, CCHE2D, Life time span, Reservoir, Sediment transport

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A.M. Negm (✉), M. Nassar, and I. Fathy
Water and Water Structures Engineering Department, Faculty of Engineering, Zagazig University, Zagazig 44519, Egypt
e-mail: amnegm85@yahoo.com; amnegm@zu.edu.eg

T. Abdel-Aziz
Nile Research Institute, NWRC, MWRI, Ashmoun, Egypt
e-mail: Aziztm@hotmail.com

A.M. Negm (ed.), *The Nile River*,
Hdb Env Chem (2017) 56: 35–56, DOI 10.1007/698_2017_2,

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1 Introduction

Reservoirs contribute by 20% of the international generation of electricity, World Commission on Dams [1]. As a result, the increasing of the lifetime of reservoirs is an urgent need. Processes of sedimentation control the lifetime of reservoirs, Morris and Fan [2]. The sedimentation processes decreased the lifetime of many reservoirs in the USA by 50:100 years, Hargrove et al. [3]. The capacity of the total reservoirs in China was decreased by 66%, Wang and Hu [4]. Moreover, the capacity of California statewide reservoir decreased by 4.5%, Minear and Kondolf [5]. Wang [6] indicated that the dams' lifetime is limited. It may reach to 100 years, Morris and Fan [2]. It was reported that the processes of sedimentation reduced the average storage capacity by 35% for 14 reservoirs in Puerto Rico, Soler-López [7] and Angulo et al. [8]. Issa et al. [9] concluded that the yearly decrease of dead and life storage capacities of Iraqi Mosul reservoir using a bathymetric survey and an analytical technique is 0.786% and 0.276%, respectively. Dalu et al. [10] detected the life of siltation for Zimbabwean Malilangwe reservoir as 100 years using the Wallingford method. Wisser et al. [11] detected the reduction of the reservoirs' capacity by 5% for international reservoirs' data sets from 1901 to 2010.

On the other hand, the parameters of sediments through AHDR were defined by Makary [12]. The volume of the deposition for AHDR through the period from 1964 to 1985 was estimated by El-Moattassem and Makary [13] to be about 1,650 Mm^3. The lifetime of AHD was expected to be 362 years, Shalash [14]. The dead zone of the reservoir was expected to be 310 years, Dahab [15]. Further investigations on the bed profile were made by Abdel-Aziz [16, 17]. In 1991, Abdel-Aziz simulated the bed profile of Aswan High Dam Reservoir in the longitudinal direction by 1D model. The bed profile of AHDR in both longitudinal and transverse directions was predicted, Abdel-Aziz [17]. The regions of the sedimentations in AHDR were defined using GIS, El-Sersawy [18]. The base map of AHDR was presented for the year 2006 by Amary [19]. Recently, Moussa [20] predicted bathymetric change along a 150 km of AHDR from 2009 to 2014 using CCHE2D. It was indicated that the maximum depositions and erosions were 3.71 m and 3.8 m, respectively.

Moreover, Hekal and Abdel-Aziz [21] recommended the use of the average transverse velocity to predict the patterns of the deposition through AHDR. Ziada

[22] indicated the important effect of the flow decrease on the analysis of the sedimentation processes. Hassan [23] found that Sudanese Merowe Dam and Ethiopian Tekeze Dam caused negative side effects on the inflow discharge to HADR. Elsahabi et al. [24] generated a 3D layer of the condensed deposition zone in Lake Nasser by remote sensing and GIS techniques. Elsaeed et al. [25] predicted the sedimentation of AHDR from 2010 to 2025 using Delft3D. It was indicated that the maximum depositions and erosions were 15.6 m and 1.75 m, respectively.

On the other hand, many studies were interested in computing the life time span of AHDR as indicated by Table 1.

In this chapter CCHE2D is applied to estimate the life time span of AHDR by investigating the sedimentation processes through the 150 km of Sudanese part (Nubia Lake). Also, the model is applied to detect lateral bed profiles for the year 2010 and the year 2020. The predicted values using CCHE2D are compared to those computed using the traditional method.

Table 1 Estimated useful life (or sediment accumulated/sediment rate) based on previous investigators since 1964 till 2016, Fathy [26] and Moussa [20]

Author	Year	Conclusion
French engineering	1891	Annual rate of sediment deposition of 1 mm on the temporarily flooded lands in Egypt
Russian engineering	Prior 1964	Dead zone 500 years
Hurst	1965	30% sand, 40% silt, and 30% clay
Ho-Khteef German Co.	1970	Dead zone 750 years
American Building Authority	1970	Dead zone 1,000 years
Abu-EL Ata	1978	Dead zone 440 years
Shalash	1980	Sedimentation 1,570 million tons during 15-year period between 1964 and1979; dead zone 362 years
Makary	1982	Dead zone 408 years and total life 1,580 years
Dahab	1982	Dead zone 310 years
El-Moattassem	1988	Sediment 1,650 million tons during 21-year period between 1964 and 1985
El-Manadely	1991	Sedimentation 2,650 million tons during 24 years
Abdel-Aziz	1997	Dead zone 311 year and life zone 1,202 years
NRI	2003	Estimated that more than 5.2 billion tons (1964–2003)
NRI	2008	Estimated that more than 6.285 billion tons (1964–2008)
Negm et al.	2010	The accumulated sediment since 1964 till 2010 is 4,936 billion M^3
Moussa	2012	The CCHE2D prediction indicated that the bed level changed with depositions ranging from 3.71 to 0.3 m and erosion ranging from 3.8 to 0.09 m. Further analysis indicated that trend of channel bed change differs only for 25% of cross sections while it remains the same for the rest of sections
Present	2016	The predicted life time span of AHDR is 964 on the year 2020

2 Study Area and Data Collection

The study is located in AHDR from km 500 to km 350 upstream High Aswan Dam with a total length of 150 km in Sudan where the delta is formed (see Fig. 1). This part includes 15 cross sections as indicated in Fig. 1. The section code, the distance of the section from upstream the AHD, the width of the section, and the length represented by the section are presented in Table 2. The bed level, velocities, discharges, and suspended concentration were collected from the Nile Research Institute (NRI), National Water Research Center (NWR), and Ministry of Irrigation and Water Resources (MIWR). The collected data were for the sections presented in Table 1. The longitudinal profile based on the lowest bed elevations of the reservoir from year 1964 to year 2007 was plotted as indicated by Fig. 2 [27]. It was observed that the thickness of the deposition layer raised by about 60 m within the last 43 years at the entrance of the reservoir.

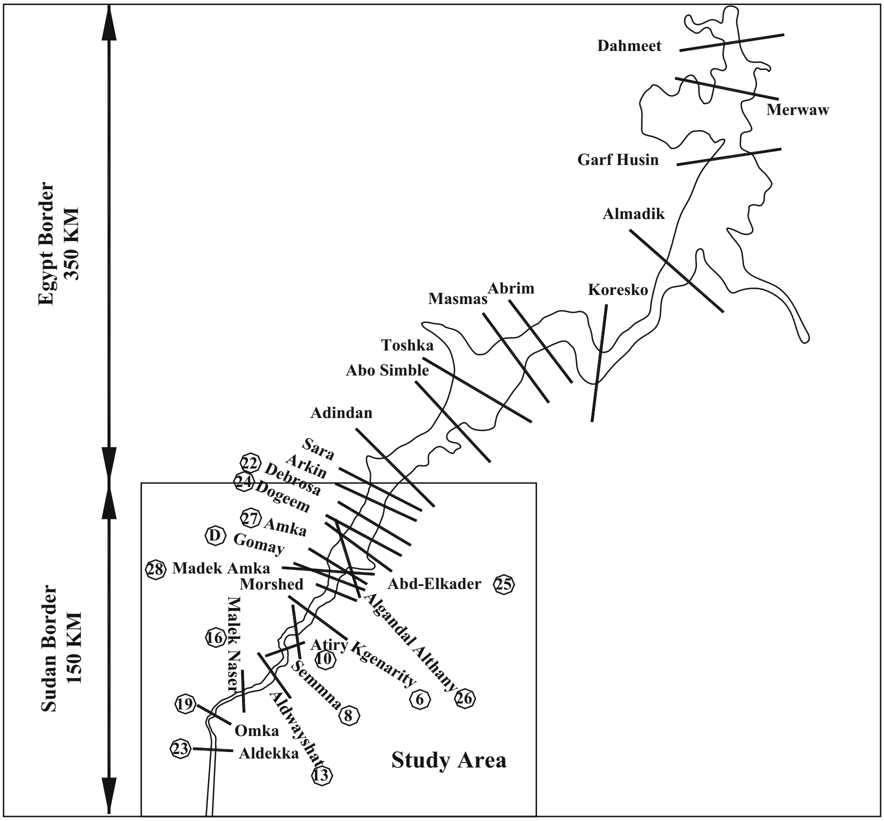

Fig. 1 A sketch for the studied area, Negm et al. [27]

Table 2 Representing length and width of each cross section, Negm et al. [27]

Section code	Name	Distance US AHD (km)	Width of cross sec (m)	Representing length (km)
23	Daka	487.50	480.0	17.00
19	Okma	466.00	610.0	19.50
16	Malik EL Nasser	448.00	1,045.0	17.50
13	EL Dowashate	431.00	1,228.50	16.25
10	Atheri	415.50	1,067.20	13.75
8	Semna	403.50	975.70	15.75
6	Kajnarity	394.00	1,281.10	12.50
3	EL Mourshed	378.50	1,278.60	11.00
D	Gami	372.00	1,605.0	5.25
28	Madik Amka	368.00	2,502.0	4.00
27	Amka	364.00	4,588.70	8.00
26	Second cataract	357.00	5,183.30	8.50
25	Abel kader	352.00	12,125.60	5.00
24	Doghim	347.00	5,559.70	7.25
22	Debrosa	337.50	9,900.0	9.00

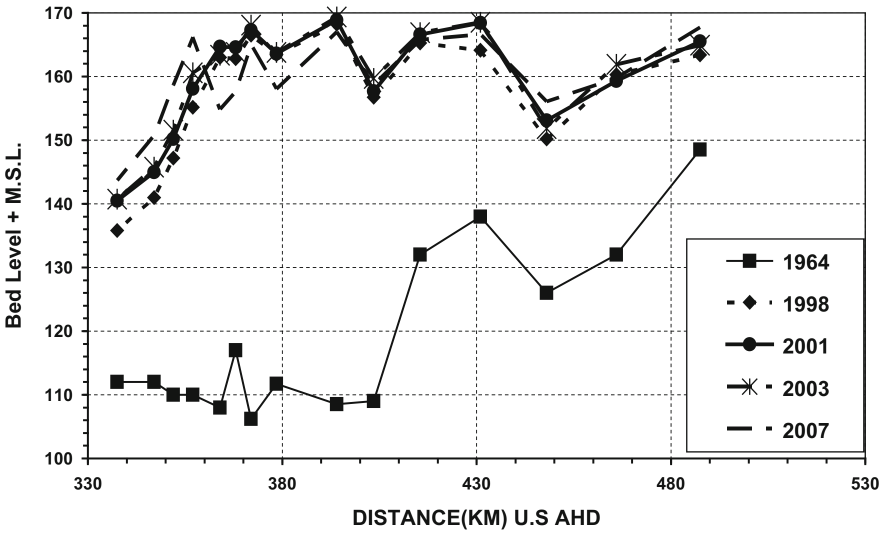

Fig. 2 Bed profile according to lowest point, Negm et al. [27]

3 Simulation Model (CCHE2D)

The CCHE2D hydrodynamic model was used to simulate the flow field. The simulation is based on the solution Navier-Stokes equations for turbulent flow. The governing equations include the momentum equations in x and y directions, the continuity equation, and sediment transport equation, Zhang [28]. The CCHE2D model is an integrated package for simulation and analysis of free surface flows, sediment transport, and morphological processes. It also includes a mesh generator (CCHE2D Mesh Generator) and a Graphical Users Interface (CCHE2D-GUI), Zhang [28]. The first module concerned with discretization of the studied area, while the second one can be considered as a visual interface. The calculation procedure of CCHE2D model can be summarized as a flowchart (see Fig. 3). The governing equations of CCHE2D used for simulating the flow field and sediment transport are continuity equation, the momentum equations in x and y directions, and sediment transport equation as presented in Eqs. (1), (2), and (3), respectively:

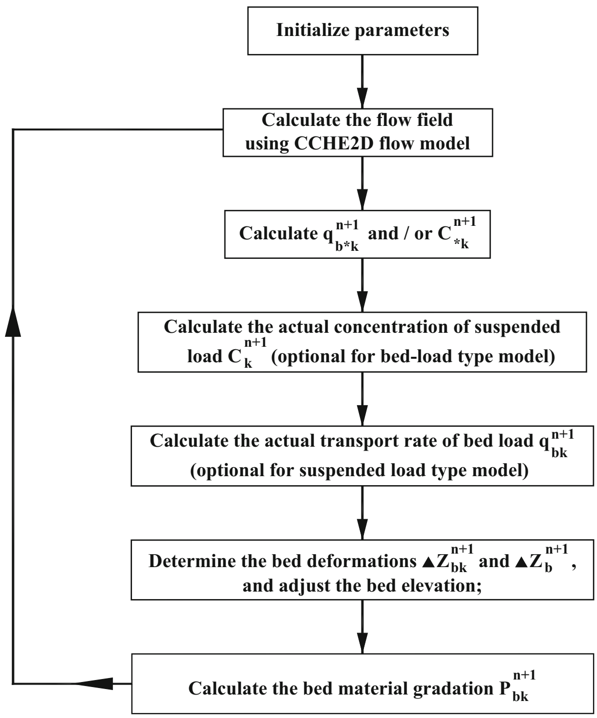

Fig. 3 Numerical model flow chart, Negm et al. [27]

Continuity equation:

$$\frac{\partial z}{\partial t}+\frac{\partial (hu)}{\partial x}+\frac{\partial (hv)}{\partial y}=0 \tag{1}$$

Momentum equations:

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=-g\frac{\partial z}{\partial x}+\frac{1}{h}\left[\frac{\partial (h\tau_{\mathrm{xx}})}{\partial x}+\frac{\partial \left(h\tau_{\mathrm{xy}}\right)}{\partial y}\right]-\frac{\tau_{\mathrm{bx}}}{\rho h}+f_{\mathrm{cor}}v \tag{2}$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=-g\ \frac{\partial z}{\partial x}+\frac{1}{h}\left[\frac{\partial\ \left(h\tau_{\mathrm{yx}}\right)}{\partial x}+\frac{\partial\ \left(h\tau_{\mathrm{yy}}\right)}{\partial y}\right]-\frac{\tau_{\mathrm{by}}}{\rho h}+f_{\mathrm{cor}}u \tag{3}$$

Sediment transport equation:

$$\frac{\partial c_k}{\partial t}+U\frac{\partial c_k}{\partial x}+v\frac{\partial c_k}{\partial y}=\varepsilon_s\left(\frac{\partial^2 c_k}{\partial x^2}+\frac{\partial^2 c_k}{\partial y^2}\right)+\frac{\alpha\omega_{sk}}{h}(C_{*k}-C_k)+S_c \tag{4}$$

where u is the depth-integrated velocity components in the x direction; v is the depth-integrated velocity components in the y directions; z is the water surface elevation; g is the gravitational acceleration; ρ is water density; h is the local water depth; f_{cor} is the Coriolis parameter; τ_{xx}, τ_{xy}, τ_{yx}, and τ_{yy} are the depth-integrated Reynolds stresses; τ_{bx} and τ_{by} are shear stresses on the bed surface; C_n is the concentration of n-th size class of sediment; S_c is the source term including the derivatives of ε_s and h; z direction being assigned as the vertical direction along the gravity; ω_{sk} is the settling velocity of the n-th size class of sediment; ε_s is the eddy diffusivity of sediment, $\varepsilon_s = v_s/\sigma_s$; V_t is the eddy viscosity of flow; σ_s is the turbulent Prandtl-Schmidt number (between 0.50 and 1.0); S_c is the source term including the derivatives of ε_s and h; C_k is the depth-averaged concentration; and C_{*k} is the transport capacity of total load.

4 Boundary and Initial Conditions

In the solutions of any partial differential equations, it is necessary to specify the initial state of functional domain and the conditions at its boundaries. For the study area, the initial conditions that are used during the simulation process are the cross sections of Lake Nasser (Sudanese sections) and its water levels that are surveyed at year 2003. Table 5 (see the Appendix) shows the surveyed data of section 23 (upstream section), and Table 6 (see the Appendix) shows the measured water level for the cross sections of the study area.

At the inlet boundary, the incoming discharges and sediment distribution may be considered if it is known, or it may be taken as uniform and equal to certain value.

Both two options are available in the model. For sediment transport under unsteady conditions, the time series of inflow sediment discharge is needed. In case of nonuniform sediment transport, the size distribution and of the inlet sediment is also needed. For the study area, the available incoming discharges, bed load, and suspended load are used as upstream boundary condition as shown in Tables 7, 8, and 9 (see the Appendix). Table 7 presents the measured water levels and discharge inside AHDR during the period of 1968–2007 so the data that are measured at years 2003–2007 are used for calibration and verification process, and for the predication process, the average discharge is used during verification process. Tables 8 and 9 present the sieve analysis results for the collected bed load and suspended load samples from the studied cross sections, respectively. For the outflow boundary, the corresponding water level of incoming discharge (rating curve) used during the study is shown in Table 7.

5 Model Calibration

The studied area has been schematized using a rectangular uniform mesh in the longitudinal direction with grid size ($x = 250$–150 m), while in the lateral direction, the grid size was ($y = 120$–50 m). It was very important to satisfy the hydrodynamic model calibration before using its velocity computations for prediction of sediment concentration. Therefore, the model was calibrated and verified using the velocity distribution and bed levels along the 15 sections of the studied area. The calibration procedure has been conducted by achieving, at first, the hydrodynamic simulation using the hydrodynamic model. The hydrodynamic simulation is accepted when the velocity distribution along the studied reach was almost the same as that measured one in the field. To achieve this step, the bed topography may be adopted within ± 0.10 m for a satisfactory simulation. Once the considered reach is well simulated, the suspended sediment concentrations, resulted from the sediment model, are in comparison to that measured in the field, which is called as verification stage. Moreover, the scour and silting zones may be detected and defined along the studied reach.

Plotting the results of all cross sections indicated that there is an acceptable agreement between the hydrodynamic model results and the field measurements. Typical plots for both measured and modeled depth-averaged flow velocity profiles and the corresponding waterway cross sections 13 and 16 are shown in Figs. 4 and 5, respectively. The statistical measures presented in Table 3 are evaluated using Microsoft Excel 2007. Figure 6a showed a comparison between the measured depth-averaged velocities and the predicted ones. A good agreement is observed. The residual values are plotted versus the predicted depth-averaged velocity as shown in Fig. 6b. The residuals show a random distribution around the line of zero.

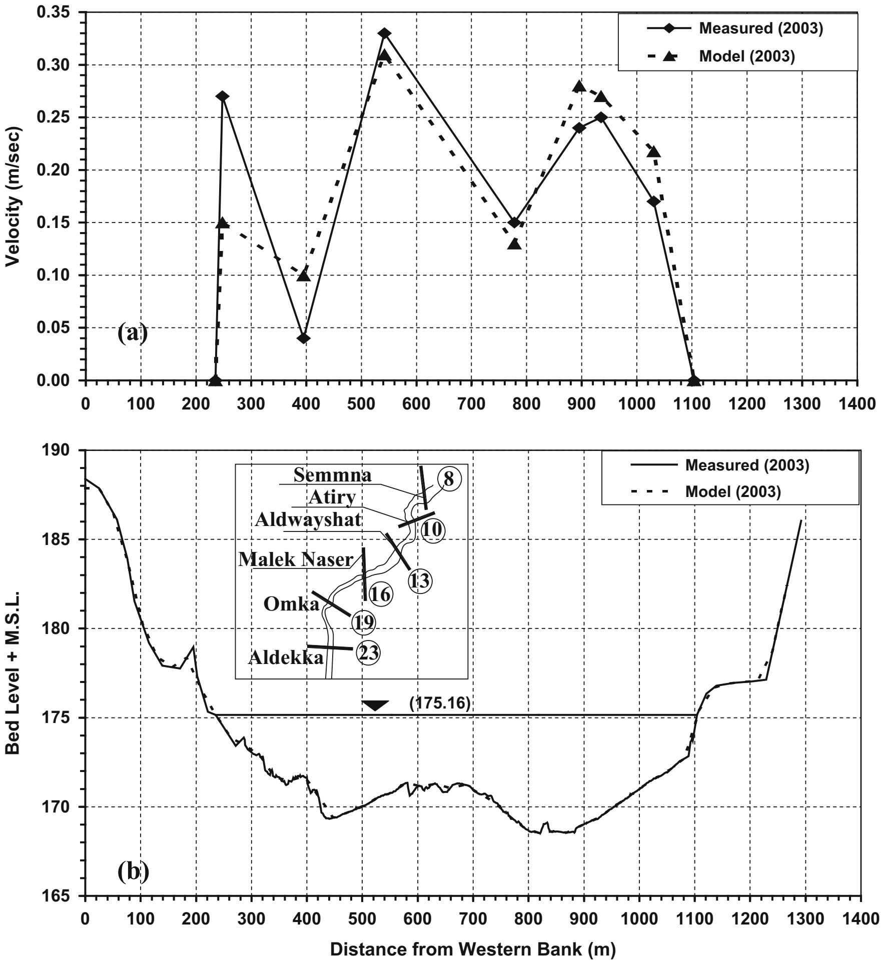

Fig. 4 (**a**) Measured velocities versus the computed ones using CCHE2D and (**b**) the measured cross section bathymetry for C.S. No. (13)

6 Model Verification

The prediction of the bed levels and the scour and silting zones are simulated using CCHE2D model. The input data includes topographic map of the studied reach, passing discharge, and the depth-averaged flow velocity field within the considered reach. The bed levels at the year 2007 are computed and compared to the field measurements at all sections. Results for two typical cross sections No.13 and No.16 are presented in Figs. 7 and 8, respectively. It can be noticed that there is an acceptable agreement between the numerical model outputs and the measurement data at the different cross sections.

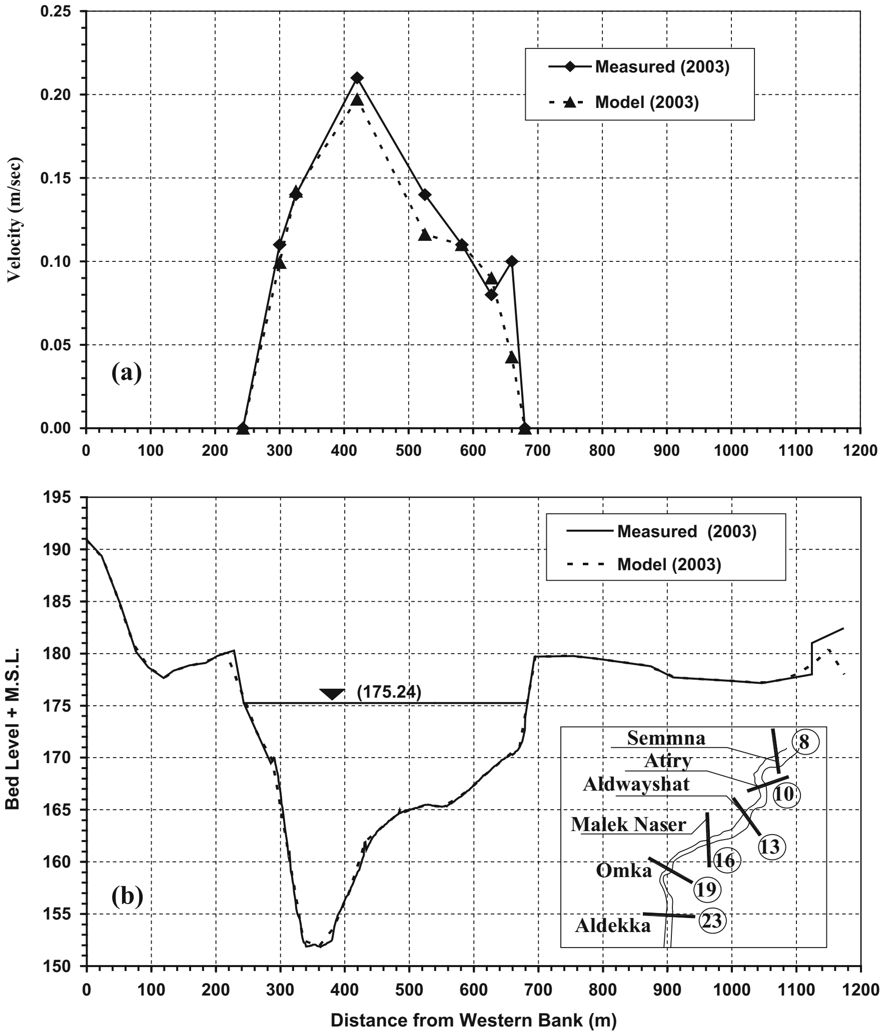

Fig. 5 (**a**) Measured velocities versus the computed ones using CCHE2D and (**b**) the measured cross section bathymetry for C.S. No. (16)

On the other hand, Fig. 9a presented a comparison between the measured bed levels and the predicted ones. An acceptable agreement is observed. The residual values are plotted versus the predicted bed levels as shown in Fig. 9b. The residuals have a random distribution around the line of zero. The statistical measures are listed in Table 2. The accuracy was more than 80%, comparing the model results and the field measurements at these sections.

Table 3 Statistical parameters for model comparison

Concept	Name	Formula	Model calibration (%)	Model verification (%)
Root m. square error	RMSE	$\sqrt{\sum_{i}^{j}(Mes - \mathrm{Pre})^2/N}$	4.47	2.00
Deter. coefficient	R2	$\sum_{i}^{j}(\mathrm{Pre} - avg.Mes)^2/\sum_{i}^{j}(Mes - avg.Mes)^2$	75.22	85.00

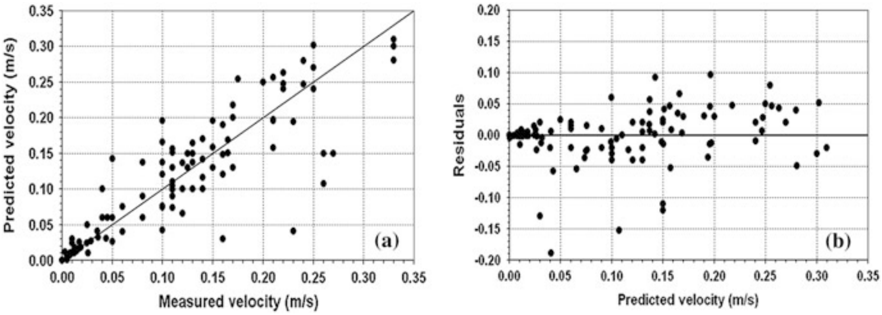

Fig. 6 (**a**) Predicted velocities in m/s versus measured ones in m/s and (**b**) variations of residuals (m/s) versus predicted values for both cross sections (13) and (16)

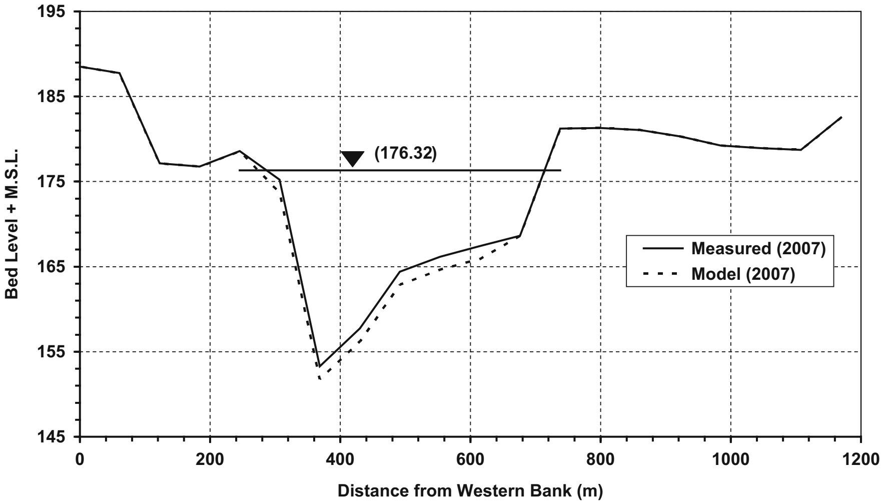

Fig. 7 Comparison between model results and the field measurements at C.S. No. 16

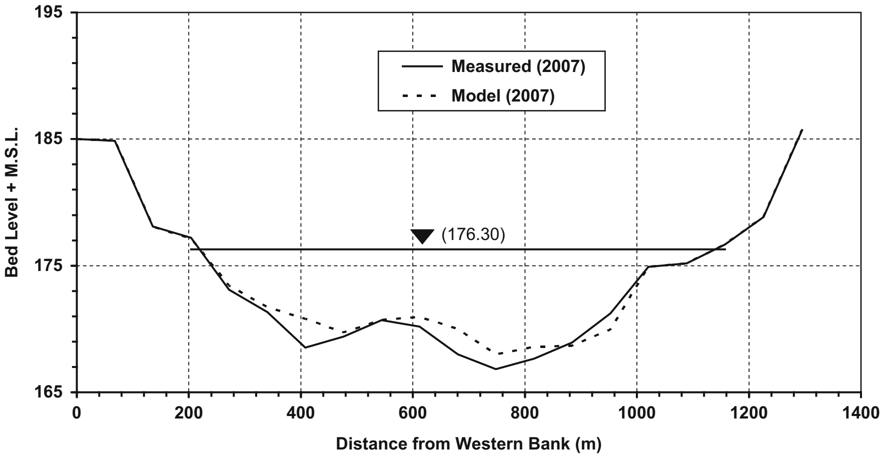

Fig. 8 Comparison between model results and the field measurements at C.S. No. 13

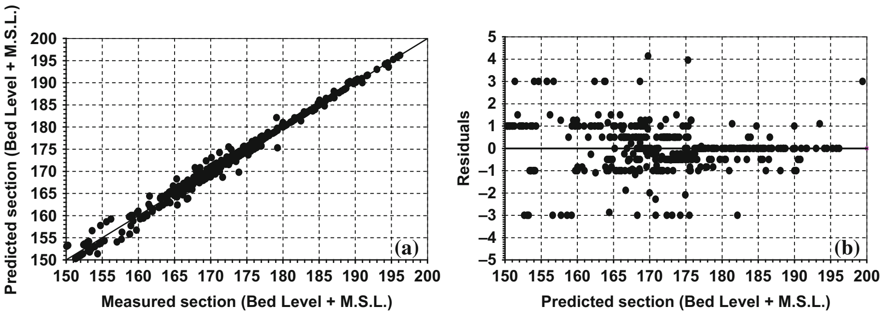

Fig. 9 (**a**) Predicted bathymetry in m versus measured ones in m and (**b**) variations of residuals (m) versus the predicted values for cross sections No. 13 and No. 16

7 Predication of Life Time Span of AHDR

The calibrated and verified CCHE2D model is applied to Nubia Lake to estimate the life time span of dead zone and life zone of the lake. In addition, the traditional method (i.e., cross-sectional method) is used to determine the life time span of the reservoir. Finally, both methods are compared.

7.1 Using the Traditional Method

Traditional method or the cross-sectional method is used to calculate the life time span of AHDR in a wide range before the year 1985 as reported in Abdel-Aziz

[16]. The procedure of the traditional method to calculate the life time span of the reservoir can be summarized as follows:

– Calculating the cross-sectional area of all sections for the year 1964 and year 2007
– Calculating deposited volume for all cross sections as indicated by Table 3
– Calculating the accumulated deposited volume in the reservoir
– Calculating the average life time span of the dead zone by dividing the designed dead storage volume of the reservoir (31.6 billion m^3) on the accumulated computed volume

The traditional method used cross sections' data for both years 1964 and 2007 to calculate the deposited area for all the 15 sections. A typical example is presented in Fig. 10 for section 19. Depending on the previous procedure and cross sections of the year 1964 and the year 2007, the accumulated deposited volume (AcDV) in Sudanese part is calculated. It equals 4,744.89 Mm^3 (see Table 3). The accumulated deposited volume in Egypt's border equals 20% of total volume deposited in Lake Nasser, Negm et al. [27]. Hence, the total accumulated volume (TAV) in the reservoir equals 5,693.9 Mm^3. The annual deposited volume in the reservoir (ADV) = AcDV/time (years) = 132.42 Mm^3/year. Finally, the life time span of dead zone (LTSDZ) = (DDSV/ADV) = 239 years. Actually, the designed life storage volume of the reservoir (DLSV) = 90.70 billion m^3. Depending on the same procedure, life time span of life zone (LTSLZ) = LTSDZ + (DLSV/ADV) = 924 years.

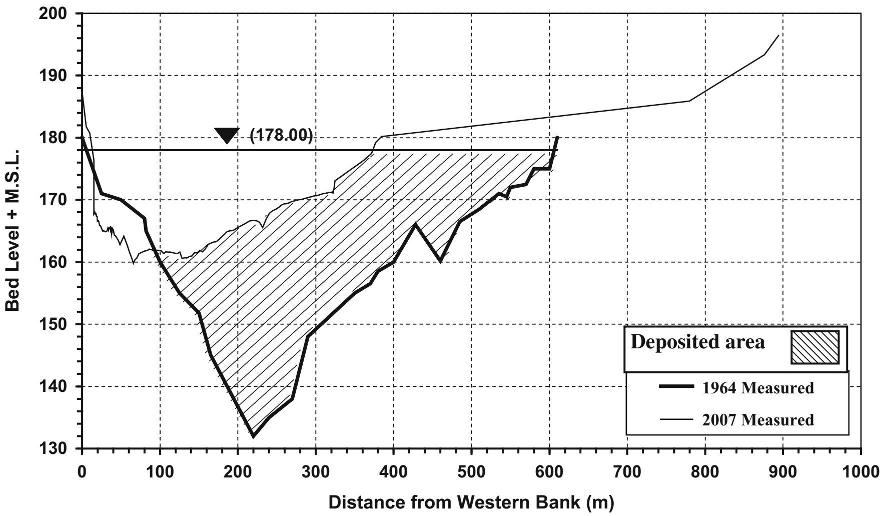

Fig. 10 Sediment accumulation at cross section 19 km 466 upstream AHD using the traditional method for the year 2007

7.2 Using the CCHE2D Simulation Model

The calibrated and verified CCHE2D model is applied to predict the different studied cross sections of Nubia Lake. The CCHE2D is used to predict all sections for the year 2010 and the year 2020. In addition, available data of cross section in year 1964 is used to calculate the deposited area for all sections.

The four trails used cross sections' data of year 1964 to calculate the deposited area; see an example in section No. 19 as shown in Figs. 11 and 12. Depending on a procedure similar to that used in the traditional method, accumulated deposited volume (AcDV) in Sudanese part, total accumulated volume (TAV), and annual deposited volume (ADV) are calculated for the four trails (see Table 3). Finally, the life time span of dead zone (LTSDZ) and life time span of life zone (LTSLZ) are calculated and tabulated in Table 4.

8 Conclusions and Recommendations

The two-dimensional numerical model CCHE2D was used to study the sedimentation processes for Nubia Lake from km 500 to km 350 upstream Aswan High Dam with a total length of 150 km. The calibrated and verified CCHE2D model is capable of simulating the sedimentation process in Nubia Lake. It has been applied to predict the different cross sections of Nubia Lake for the year 2010 and the year 2020. The results were used to estimate the life time span. The life time span of

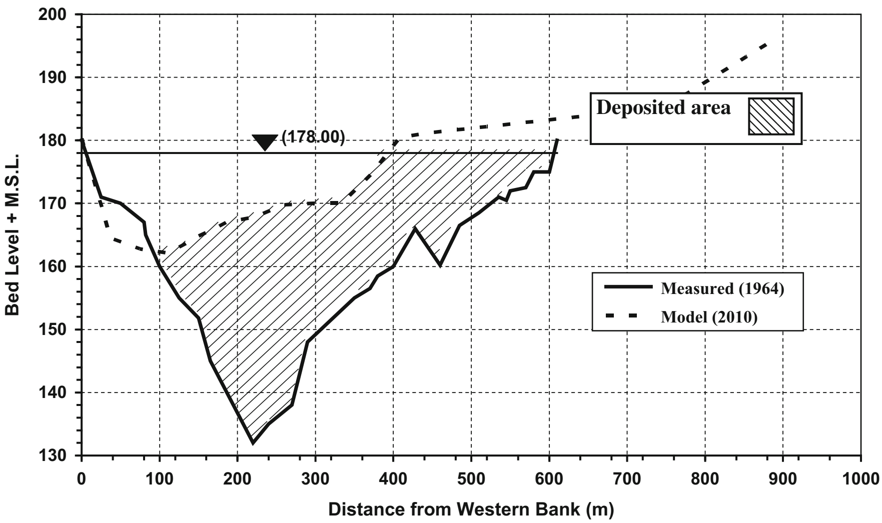

Fig. 11 Sediment accumulation at cross section 19 km 466 upstream AHD using the CCHE2D for the year 2010

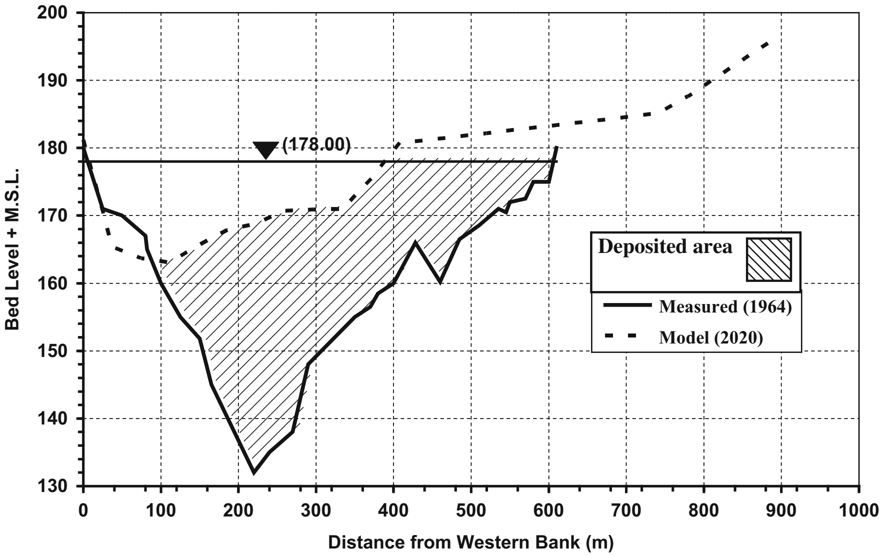

Fig. 12 Sediment accumulation at cross section 19 km 466 US AHD using the CCHE2D for the year 2020

dead zone, LTSDZ, is equal to 254 years, and the life time span of life zone, LTSLZ, is equal to 964 years. It should be noted that this life time span will not be significantly affected in the future due to the fact that after the construction of the GERD which will retain the sediment in its reservoir. However, the pattern of the accumulated sediment in the lake will be modified as a result of the almost clear coming inflow to AHDR. The authors highly recommend a hydrodynamic study to investigate the change in the sedimentation patterns due to different scenarios of the sediment concentration of incoming flow.

Acknowledgment The authors would like to thank the Water Technology Association (WTA) for the permission to republish some of the materials of the paper titled ""Predication of life time span of high Aswan dam reservoir using CCHE2D simulation model"" that was presented at the 14th International Water Technology Conference (IWTC14).

Table 4 Computed life time span via the computations of the deposited volumes in AHDR for the periods 1964–2007 (using the traditional method), 1964–2010, and 1964–2020 (using the CCHE2D)

Sec. code	Sec. length (km)	Dep. Vol. (Mm^3) Traditional 1964–2007	Dep. Vol. (Mm^3) CCHE2D 1964–2010	Dep. Vol. (Mm^3) CCHE2D 1964–2020
23	23.25	108.83	113.99	128.02
19	19.75	158.23	162.41	169.52
16	17.50	241.51	249.92	265.01
13	16.25	297.92	306.79	323.13
10	13.75	325.55	331.64	344.13
8	10.75	229.42	232.75	246.80
6	12.50	306.28	301.82	327.79
3	11.00	348.95	357.19	594.47
D	5.25	194.68	200.05	260.26
28	4.00	224.00	236.38	286.68
27	5.50	571.68	605.97	698.64
26	6.00	731.12	763.65	825.78
25	5.00	193.14	215.93	391.89
24	7.25	601.88	634.98	794.05
22	4.75	211.7	222.27	262.32
Sud. AcDV (Mm^3)		4,744.89	4,936.00	5,918.50
TAV (Mm^3)		5,693.90	5,922.89	7,102.18
ADV (years)		132.42	128.75	126.82
LTSDZ (years)		239	245	249
LTSLZ (years)		924	949	964

Appendix: Initial and Boundary Conditions Data of Section 4

See Tables 5–9.

Table 5 Typical surveyed coordinates of C.S. No. 23 (378.5 km US AHD) NRI [29]

x	Y	x	y	x	y	x	y	X	y
0	196.19	162.57	171.02	238.26	169.34	278.99	168.66	444.45	168.49
8	195.8	164.13	170.92	240.97	169.21	281.64	168.84	445.89	168.40
54.32	192.26	165.49	170.81	243.69	169.36	281.95	168.79	447.21	168.49
105	186.7	166.70	170.60	246.42	169.47	284.32	168.59	447.44	168.21
112.05	176.4	167.86	170.68	249.15	169.78	285.30	168.67	448.99	168.49
128.32	172.62	169.00	170.54	251.85	169.65	287.02	168.82	450.04	168.16
130.68	172.43	170.18	170.36	254.56	169.72	288.62	168.84	450.53	168.44
133.01	172.24	171.39	170.48	257.28	169.72	289.77	168.83	452.04	168.22
135.48	171.90	172.65	170.44	260.06	169.62	291.89	168.79	452.75	168.20
138.02	171.77	173.93	170.33	263.04	169.44	292.56	168.84	453.55	168.48
140.63	171.39	175.20	170.24	265.98	169.25	295.30	168.76	476.3	176.4
143.28	171.20	176.44	170.04	266.11	169.17	295.32	168.82	480.55	178.94
145.95	171.24	177.69	169.94	268.58	169.08	298.08	168.80	484.76	181.26
148.85	171.21	179.01	169.88	269.20	168.98	298.62	168.79	488.52	182.69
151.53	171.11	180.41	170.13	271.16	168.92	300.80	168.79	580.35	182.98
154.12	170.96	181.84	170.08	272.38	169.32	302.28	168.82	632.6	183.25
156.55	171.16	223.12	170.04	273.75	169.27	303.53	168.82	687.93	185.14
158.78	171.22	225.45	170.00	275.45	169.18	305.62	168.82	700.91	186.04
160.78	171.07	227.88	170.04	276.37	169.09	306.28	168.88	714.51	187.21

Table 6 Velocity and water level at the cross sections of the study area, NRI [29]

C.S. code	Name	Distance US AHD (km)	Date	Mean velocity (m/s)	Water level at section (m)
23	Daka	487.50	6/5/2003	0.41	175.55
19	Okma	466.00	7/5/2003	0.34	175.51
16	Malik EL Nasser	448.00	8/5/2003	0.25	175.24
13	EL Dowashate	431.00	9/5/2003	0.32	175.16
10	Atheri	415.50	10/5/2003	0.26	175.10
8	Semna	403.50	11/5/2003	0.20	175.08
6	Kajnarity	394.00	12/5/2003	0.18	175.03
3	Mourshed	378.50	13/5/2003	0.21	174.95
D	Gomi	372.00	14/5/2003	0.16	174.93
28	Madik Amka	368.00	15/5/2003	0.23	174.90
27	Amka	364.00	15/5/2003	0.18	174.90
26	Second cataract	357.00	16/5/2003	0.05	174.87
25	Abel kader	352.00	17/5/2003	0.05	174.84
24	Doghim	347.00	18/5/2003	0.08	174.82
22	Debrosa	337.50	19/5/2003	0.08	174.80

Table 7 Measured water level and discharge in AHDR, Amary [19]

Years		Discharge BCM	Water level (m)	Years		Average discharge BCM	Average water level (m)
1968	1969	80.96	151.1	1988	1989	110.85	164.41
1969	1970	82.38	153.83	1989	1990	75.8	163.77
1970	1971	91.91	159.68	1990	1991	70.04	162.5
1971	1972	90.43	162.49	1991	1992	81.86	163.98
1972	1973	64.47	158.2	1992	1993	88.07	167.45
1973	1974	89.73	161.71	1993	1994	91.19	169.64
1974	1975	95.26	165.6	1994	1995	94.59	172.34
1975	1976	115.71	172.42	1995	1996	81.38	172.76
1976	1977	80.47	171.7	1996	1997	95.55	175.5
1977	1978	90.55	172.52	1997	1998	73.53	174.75
1978	1979	85.28	173.04	1998	1999	120.62	175.79
1979	1980	70.5	171.27	1999	2000	107.47	175.85
1980	1981	79.51	171.13	2000	2001	94.75	175.7
1981	1982	81.76	170.36	2001	2002	95.58	175.14
1982	1983	64.88	165.87	2002	2003	71.1	172.06
1983	1984	73.19	163.6	2003	2004	80.13	171.8
1984	1985	56.38	156.37	2004	2005	72.73	169.59
1985	1986	78.69	157.23	2005	2006	76.88	168.65
1986	1987	66.86	154.65	2006	2007	105.42	173.42
1987	1988	63.08	151.7				

Table 8 Sieve analysis of bed samples, Makary [12]

Sec. (23)	Diameter (mm)	0.1	0.2	0.3	0.5
	Passing age%	2	8	40	50
Sec. (19)	Diameter (mm)	0.01	0.1	0.17	0.3
	Passing age%	3	19	48	30
Sec. (16)	Diameter (mm)	0.1	0.17	0.2	0.3
	Passing age%	10	40	30	20
Sec. (13)	Diameter (mm)	0.001	0.01	0.1	0.4
	Passing age%	3	6	21	70
Sec. (10)	Diameter (mm)	0.0001	0.001	0.01	0.1
	Passing age%	8	32	30	30
Sec. (8)	Diameter (mm)	0.0001	0.001	0.01	0.1
	Percentage %	3	15	22	60
Sec. (6)	Diameter (mm)	0.0001	0.001	0.01	0.1
	Passing age%	5	27	41	27
Sec. (3)	Diameter (mm)	0.0001	0.001	0.01	0.1
	Passing age%	5	35	42	18
Sec. (D)	Diameter (mm)	0.0001	0.001	0.01	0.1
	Passing age%	5	30	35	30
Sec. (28)	Diameter (mm)	0.0001	0.001	0.01	0.1

(continued)

Table 8 (continued)

	Passing age%	3	22	40	35
Sec. (27)	Diameter (mm)	0.0001	0.001	0.01	0.1
	Passing age%	5	35	40	20
Sec. (26)	Diameter (mm)	0.0001	0.001	0.01	0.1
	Passing age%	5	27	43	25
Sec. (25)	Diameter (mm)	0.0001	0.001	0.01	0.1
	Passing age%	7	38	40	15
Sec. (24)	Diameter (mm)	0.0001	0.001	0.01	0.1
	Passing age%	7	33	48	12
Sec. (22)	Diameter (mm)	0.0001	0.001	0.01	0.1
	Passing age%	10	55	23	12

Table 9 Sieve analysis of suspended samples, Makary [12]

Sec. (23)	Diameter (mm)	0.000001	0.00001	0.000001	0.00001
	Passing age%	5	55	5	55
Sec. (19)	Diameter (mm)	0.000001	0.00001	0.000001	0.00001
	Passing age%	0	30	0	30
Sec. (16)	Diameter (mm)	0.000001	0.00001	0.000001	0.00001
	Passing age%	5	45	5	45
Sec. (13)	Diameter (mm)	0.000001	0.00001	0.000001	0.00001
	Passing age%	22	48	22	48
Sec. (10)	Diameter (mm)	0.000002	0.00001	0.000002	0.00001
	Passing age%	8	47	8	47
Sec. (8)	Diameter (mm)	0.000001	0.00001	0.000001	0.00001
	Percentage %	0	15	0	15
Sec. (6)	Diameter (mm)	0.000001	0.00001	0.000001	0.00001
	Passing age%	42	28	42	28
Sec. (3)	Diameter (mm)	0.000001	0.00001	0.000001	0.00001
	Passing age%	30	30	30	30
Sec. (D)	Diameter (mm)	0.000001	0.00001	0.000001	0.00001
	Passing age%	30	30	30	30
Sec. (28)	Diameter (mm)	0.000001	0.00001	0.000001	0.00001
	Passing age%	30	30	30	30
Sec. (27)	Diameter (mm)	0.000001	0.00001	0.000001	0.00001
	Passing age%	30	30	30	30
Sec. (26)	Diameter (mm)	0.000001	0.00001	0.000001	0.00001
	Passing age%	30	30	30	30
Sec. (25)	Diameter (mm)	0.000001	0.00001	0.000001	0.00001
	Passing age%	30	30	30	30
Sec. (24)	Diameter (mm)	0.000001	0.00001	0.000001	0.00001
	Passing age%	30	30	30	30
Sec. (22)	Diameter (mm)	0.000001	0.00001	0.000001	0.00001
	Passing age%	30	30	30	30

References

1. World Commission on Dams (2000) Dams and development: a framework for decision making. Report. Earthscan, London
2. Morris G, Fan J (1998) Reservoir sedimentation handbook. McGraw-Hill, New York
3. Hargrove W, Johnson D, Snethen D, Middendorf J (2010) From dust bowl to mud bowl: sedimentation, conservation measures, and the future of reservoirs. J Soil Water Conserv 65 (1):14A–17A. doi:10.2489/jswc.65.1.14A
4. Wang Z, Hu C (2009) Strategies for managing reservoir sedimentation. Int J Sediment Res 24 (4):369–384. doi:10.1016/S1001-6279
5. Minear J, Kondolf G (2009) Estimating reservoir sedimentation rates at large spatial and temporal scales: a case study of California. Water Resour Res 45:W12502. doi:10.1029/2007WR006703
6. Wang G (2005) Sedimentation problems and management strategies of Sanmenxia Reservoir, Yellow River, China. Water Resour Res 41:W09417. doi:10.1029/2004WR003919
7. Soler-López LR (2001) Sedimentation survey results of the principal water-supply reservoirs of Puerto Rico, USGS Water Resources of the Caribbean. http://vi.water.usgs.gov/public/reports/soler.html
8. Angulo J, Jenkins A, Lebedev A, McNeff N (2015) Assessing the lifespans of reservoirs in region 2 of Puerto Rico. Annual report, 2015. Worcester Polytechnic Institute, Worcester
9. Issa E, Al-Ansari N, Sherwany G, Knutsson S (2013) Sedimentation processes and useful life of Mosul Dam Reservoir, Iraq. Eng J 5:779–784
10. Dalu T, Tambara E, Clegg B, Chari L, Nhiwatiwa T (2013) Modeling sedimentation rates of Malilangwe reservoir in the south-eastern lowveld of Zimbabwe. Appl Water Sci 3:133–144. doi:10.1007/s13201-012-0067-9
11. Wisser D, Frolking S, Hagen S, Bierkens M (2013) Beyond peak reservoir storage? A global estimate of declining water storage capacity in large reservoirs. Water Resour Res 49:5732–5739. doi:10.1002/wrcr.20452
12. Makary A (1982) Sedimentation in the High Aswan Dam Reservoir. Ph.D. thesis, Faculty of Engineering, Ain Shams University, Egypt
13. El-Moattassem M, Makary A (1988) Sedimentation balance in the Aswan High Dam Reservoir. Report 110 NRI. Cairo, Egypt
14. Shalash S (1980) Effect of sedimentation on storage capacity of high Aswan Dam Lake. Paper No. 56, El-Qanater, Egypt
15. Dahab A (1983) Lake Nasser area between Abu-Simble and Dall cataract. Ph.D. thesis, University of Ain Shams, Egypt
16. Abdel-Aziz TM (1991) Numerical modeling of sediment transport and consolidation in the Aswan High Dam Reservoir. M.Sc. thesis, Laboratory of hydrology, Free University of Brussels, VUB, Belgium
17. Abdel-Aziz TM (1997) Prediction of bed profile in the longitudinal and transverse direction in Aswan High Dam Reservoir. Ph.D. thesis, Cairo University, Giza, Egypt
18. El-Sersawy H (2005) Development of decision support system (D.S.S) for Aswan High Dam Reservoir sedimentation. National Water Research Center (N.W.R.C.), Cairo
19. Amary W (2008) Study the sedimentation inside High Aswan Dam Reservoir. M.Sc. thesis, Faculty of Engineering, Cairo University, Egypt
20. Moussa A (2012) Predicting the deposition in the Aswan High Dam Reservoir using a 2-D model. Ain Shams Eng J 4(2):143–153
21. Hekal N, Abdel-Aziz TM (2015) Effect of transverse water velocity distribution on sedimentation at Aswan High Dam Reservoir. In: Fifteenth international water technology conference, IWTC15. www.iwtc.info
22. Ziada W (2016) Sedimentation analysis for Aswan High Dam Reservoir. Ph.D. thesis, Benha University, Egypt

23. Hassan WE (2015) Impact of the upper River Nile projects on the lake of High Aswan Dam. Ph.D. thesis, Al-Azhar University, Cairo, Egypt
24. Elsahabi M, Negm AM, Ali K (2016) Correlating the velocity profiles to the sediment profiles of the active sedimentation zone of Aswan High Dam Lake. In: Nineteenth international water technology conference, IWTC19, Sharm El Sheikh. http://www.iwtc.info
25. Elsaeed G, Aziz M, Ziada W (2016) Sedimentation analysis and prediction for Aswan High Dam Reservoir. J Sci Eng Res 3(4):302–312
26. Fathy I (2010) Evaluation of water resources projects in Egypt. M.Sc. thesis, Faculty of Engineering, Zagazig University, Egypt
27. Negm AM, Abdulaziz T, Nassar M, Fathy I (2010) Predication of life time span of High Aswan Dam Reservoir using CCHE2D simulation model. In: 14th International water technology conference, IWTC 14, Cairo, Egypt, pp 611–626
28. Zhang Y (2005) CCHE2D-GUI – graphical user interface for the CCHE2D model. User's manual – version 2.2. Technical Report No. NCCHE-TR-2005-03, The University of Mississippi
29. NRI (2003) Aswan High Dam Lake. Final report, Nile Research Institute, National Water Research Center, Ministry of Water Resources and Irrigation, El-Qanater, Egypt

A Satellite Remote Sensing Approach to Estimate the Lifetime Span of Aswan High Dam Reservoir

Abdelazim Negm, Mohamed Elsahabi, and Kamal Ali

Abstract Aswan High Dam Reservoir (AHDR) is vital to Egypt. It is the main source of freshwater for Egypt. The main objectives of the present study are to assess the sedimentation rate and to determine the reduction in the reservoire storage capacity for the live and dead zones of AHDR using remote sensing (RS) and geographic information systems (GIS). These results will be used to compute the lifetime span (LTS) of both the dead and live storage zones. The computed values using RS and GIS are compared with those of the cross-section method computed adopted by the Aswan High Dam Authority (AHDA). The present study indicated that the annual sediment deposition rate in the AHDR is 147.29×10^6 m^3/yr of which 65.49×10^6 and 81.80×10^6 m^3/yr in dead and live storage zones, respectively. This implies that the annual reduction rates in the dead and live storage capacities of this reservoir are 0.208% and 0.121%, respectively. Moreover, the results showed that the computed value of LTS of the dead zone is 482 years while the LTS of the live zone is 830 years. As a consequence, the sediment trap (dead zone) efficiency of AHDR will be decreased by 20.75% every 100 years of operation of the AHD. Furthermore, the AHDA estimated that the dead storage and live storage zones would be filled with sediments in 487 and 835 years, respectively. This indicates that the results of the present study and the AHDA approach are very close.

A. Negm (✉)
Water and Water Engineering Department, Faculty of Engineering, Zagazig University, Zagazig 44519, Egypt
e-mail: amnegm85@yahoo.com; amnegm@zu.edu.eg

M. Elsahabi
Civil Engineering Department, Faculty of Engineering, Aswan University, Aswan, Egypt
e-mail: mohamed.sahabi@aswu.edu.eg

K. Ali
Civil Engineering Department, Faculty of Engineering, Aswan University, Aswan, Egypt
e-mail: kamalabbas90@yahoo.com

A.M. Negm (ed.), *The Nile River*,
Hdb Env Chem (2017) 56: 57–78, DOI 10.1007/698_2017_15,

Keywords AHDR, GIS, Lifetime span, Remote sensing, Sedimentation

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Abbreviations

AHD	Aswan High Dam
AHDA	Aswan High Dam Authority
AHDL	Aswan High Dam Reservoir
BCM	Billion cubic meters, B m^3
DZ	Dead zone
GIS	Geographic information systems
km	Kilometer
LTS	Lifetime span
LZ	Live zone
M m^3	Million cubic meter
MAE	Mean absolute error
RS	Remote sensing
yr	Year

1 Introduction

The primary functions of reservoirs, as one of the water resources components, are to smoothen out the variability of surface water flow through control and regulation and make water available when and where needed. Reservoirs have well-known primary purposes such as water supply, irrigation, flood control, hydropower, and navigation [1]. Reservoir sedimentation and consequent loss of its storage capacity affect directly the future performance of the reservoir [2]. Consequently, it is of prime importance to monitor the rate of sedimentation and the changes in the capacity of reservoirs with time in order to estimate their lifetime span (LTS). It is well established the fact that reservoirs constructed on rivers are subjected to sedimentation. Reservoir sedimentation is a natural phenomenon. All the reservoirs suffer a loss in their potential storage because of silt load, over a period of time [3].

The LTS of a reservoir is the period during which the sediment collected does not affect the intended primary use of this reservoir. It is considered an important design parameter of reservoirs which may affect the sustainability of these water resources [1]. The LTS of any dam reservoir can be determined by estimating the rate of sedimentation which ultimately reduces the storage capacity of such reservoir.

The Aswan High Dam Reservoir (AHDR) is considered one of the most important components of the water resources systems in Egypt. It regulates the discharge downstream of the AHD to match the actual water needs for different requirements of the country [4]. The AHDR had been subjected to reduction in its storage capacity due to sediment deposition.

Based on the reviewed literature, it had been found that the storage capacity loss in reservoirs due to sediment deposition was estimated by many researchers (e.g., Issa [2], EL-Sersawy [5], and Bhavsar [6]).

Issa [2] concluded that the Mosul dam reservoir (Iraq) lost about 6.9 and 19.66% of its live and dead storage capacity zones during 25 years of operation of the dam. EL-Sersawy [5] found that the Roseires reservoir (Sudan) lost about 36% of its storage capacity during 28 years of operation. Bhavsar [6] concluded that the capacity loss of Sukhi reservoir (India) is about 3.244 M m^3/yr (6.21%) from the year 2005 to the year 2010.

On the other hand, there were some studies associated with estimating the LTS of reservoirs (e.g., Negm et al. [7], Garg [1], and Abdel-Aziz [8]).

Negm et al. [7] concluded that LTS of AHDR dead zone is 254 years, while LTS of its live zone is 964 years by establishing a two-dimensional numerical simulation model (CCHE2D) to study the sedimentation processes in Lake Nubia. Garg [1] proved that the dead storage zone of Gobindsagar reservoir (India) would be filled with sediment in 95 years (LTS of the dead zone). Abdel-Aziz [8] found that the LTS of AHDR was about 311 years and 1,202 years for the dead and live zones, respectively, by predicting the bed profile of the AHD reservoir in both longitudinal and transverse directions.

Satellite observations data have been combined with in-situ measurements, using GIS analyst tools, to estimate and analyze changes in reservoirs bed surfaces (sedimentation and erosion), with successful applications in different parts of the world [9]. Monitoring AHDR through satellite images and using GIS techniques is very important in the management and operation of the reservoir and its relevant projects [10]. Therefore, the current chapter is presented for assessing the sedimentation rate and determining the reduction in the storage capacity for the dead and live zones of AHDR in order to estimate the LTS of these zones using RS and GIS techniques.

2 Description of the Study Area

Based on the 1959 Nile Waters Agreement between Sudan and Egypt, AHD was constructed to completely control the Nile water for the benefit of the two countries. The AHD is a rockfill dam, completed in 1968 and fully operated in 1972. It is located 7.0 km south of Aswan City [4]. The AHDR is the study area in this chapter. It is one of the greatest man-made reservoirs in the world, created after the construction of the Aswan High Dam (AHD). This reservoir extends for 500 km along the Nile River from the southern part of Egypt to the northern part of Sudan. It covers an area of about 6,000 km^2, of which two-thirds (known as Lake Nasser, 350 km) is in Egypt and one-third (called Lake Nubia, 150 km) is in Sudan [4] as shown in Fig. 1. Table 1 gives further characteristics of AHDR.

Moreover, the AHDR designed storage capacity (162 billion m^3) is distributed as follows [4]:

- 31.6 BCM: dead storage between level 85 and 147 m.
- 90.7 BCM: live storage capacity between level 147 and 175 m.
- 39.7 BCM: flood control storage capacity between levels of 175 and 182 m.

2.1 The First Part (Lake Nasser)

Lake Nasser is the Egyptian part of the AHDR. It is located between latitude 22° 00′ 00″ N (upstream the AHD) and the AHD in the north as presented in Fig. 1. The measurements (hydrographic survey data) cover only the distance that extends from the end of Lake Nubia in Sudan to km 123 upstream the AHD in Egypt (behind which no sedimentation is observed) [12]. For thus, the chosen part within Lake Nasser, which was considered in the present study (part 1), extends from latitude 22° 00′ 00″ N to km 123 upstream the AHD, as shown in Fig. 2.

Fig. 1 The Aswan High Dam Reservoir (AHDR) map

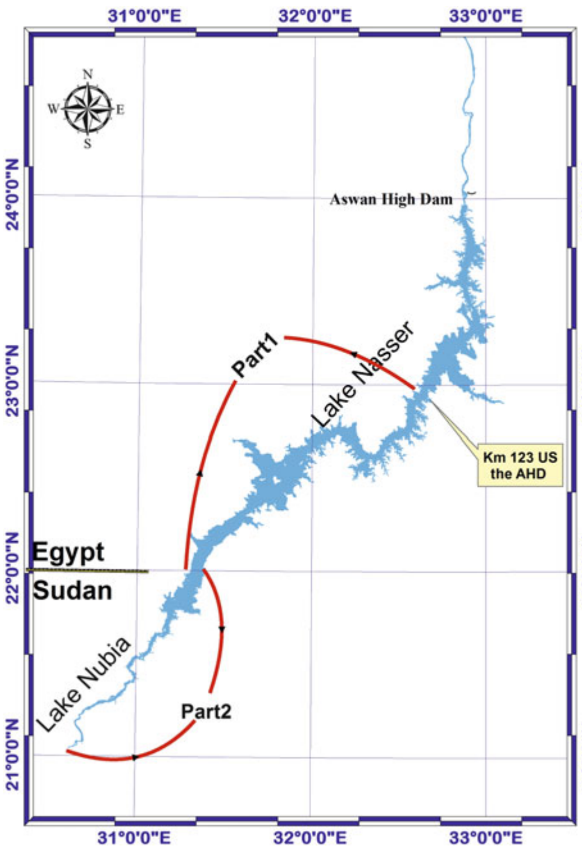

Table 1 Characteristics of the Aswan High Dam Reservoir (AHDR) [11]

Characteristics	Values
Max length (km)	500
Max width (km)	12
Maximum depth (m)	110
Mean depth (m)	70
Water volume (B m^3)	162
Average annual inflow (B m^3/yr)	70
Major water uses	Irrigation, hydropower

2.2 *The Second Part (Lake Nubia)*

Lake Nubia is the Sudanese part of the AHDR (part 2) as given in Fig. 1. It is located between latitudes 21° 02′ 00″ and 22° 00′ 00″ N (upstream the AHD). The

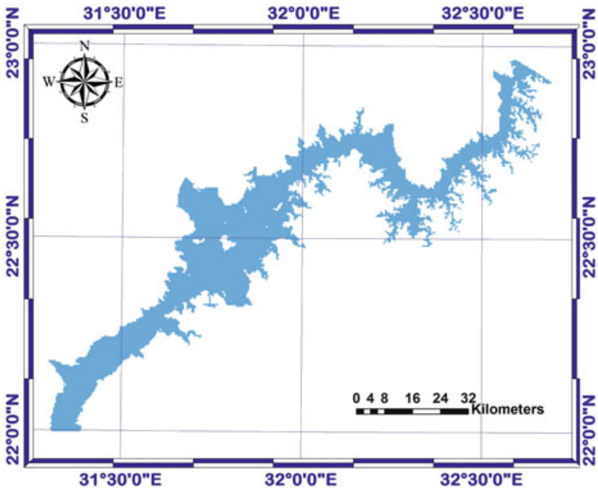

Fig. 2 Location of the first part of the study area within Lake Nasser

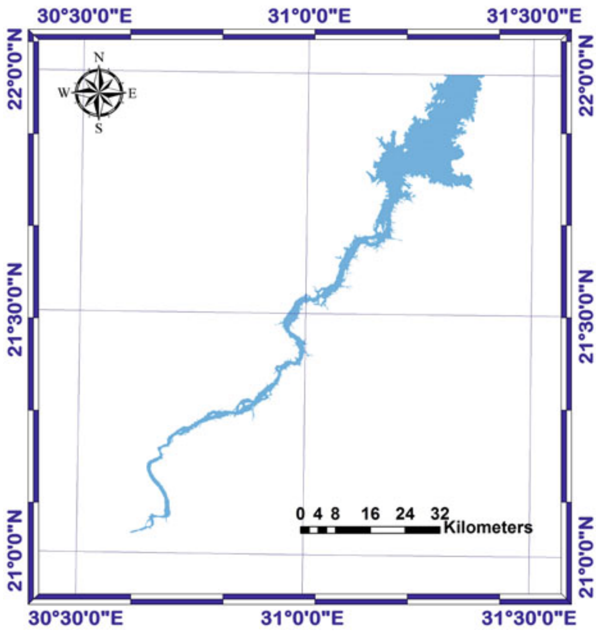

Fig. 3 Location of the second part of the AHDR (Lake Nubia)

southern two-thirds of this Lake are narrow, while the remaining northern part is much wider [13] as indicated in Fig. 3.

3 Collected Data

3.1 Bathymetric Data

These data describe the geometry of AHDR and include:

3.1.1 Hydrographic Survey Data

The hydrographic survey data (bathymetry) presented by Easting, Northing, and Elevation (E, N, and Z) were used to describe the geometry of AHDR (part 1 and part 2) for the year 2012. These data were collected using the echo-sounder measurements system by AHDA, NRI [12].

3.1.2 Topographic Maps

The available old topographic maps of the Nile River at the study area that were surveyed in the year 1944 (with scale 1:100,000) and in the 1949 (with scale 1:25,000) are considered the source of levels points that describe the geometry of AHDR at the beginning of the storage process in the reservoir. These maps contain contour lines that represent levels of the two lakes before AHD construction.

3.2 Sediment Data

Whereas water has been storing since 1964 in AHDR, the measurements of bed levels taken in 1964 (field measurements, see Fig. 4) are added to the (1944/1949)

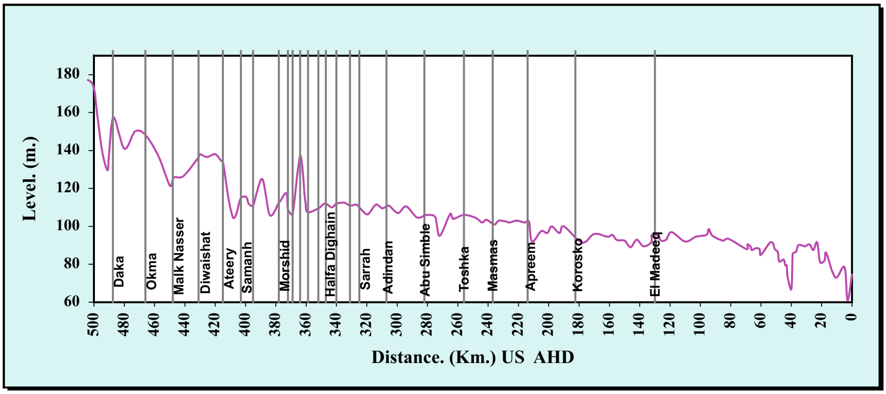

Fig. 4 Longitudinal section in AHDR deepest points in the year 1964 [12]

Table 2 The specifications of Landsat ETM+ images

Satellite	Sensor	Path/row	Date	Spatial resolution	Water level (m)
Landsat-7	ETM+	175/045	September 2000	30 m	178
		175/045	March 2006		173
		175/045	March 2009		176
		174/044	March 2005		174
		174/044	November 2001		180
		175/044	September 2000		178
		175/044	April 2006		172
		175/044	March 2009		176

dataset as the lowest bed for sediment to make the bed surface closer to the 1964s surface as much as possible.

3.3 Remote Sensing Data

The remote sensing data (Eight Landsat ETM+ images) are used in this study to extract the reservoir boundaries. One scene of a Landsat image can entirely cover the second part of the AHDR with (Path/Row = 175/045), while three scenes are needed to completely cover the first part with (Path/Row = 175/045, 174/044, and 175/044). The specifications of the acquired images for the two parts of the study area are given in Table 2. The data were downloaded freely from the United States Geological Survey (USGS) earth explorer website [14] in Geotiff (systematic correction) product. The collected images are free from geometric, radiometric, and noise errors. These images were geo-referenced by USGS using the world reference system (WGS-84 datum) to Universal Transverse Mercator (UTM) system zone, 36 North projection.

3.4 Water Levels Data

Water levels upstream AHD were recorded by AHDA gauge stations in the different dates of the year [15]. These data were collected to help in detecting the water surface levels of the reservoir at the dates of acquiring the satellite images.

4 Methodology

This section describes the steps used by the authors to achieve the objectives of the present chapter. The flowchart presented in Fig. 5 summarizes the methodology of the study.

4.1 Water Surface Areas Extraction

The unsupervised classification technique of Landsat data is performed to obtain the water texture of AHDR, because it is considered the best technique for water bodies recognition [13, 16, 17].

The extracted reservoir boundaries, obtained from the satellite images, were used to form the shape of the surface and also to form a group of scattering points (x, y,z) using the WGS84, UTM Z36N as a defined projected coordinate system. These points were used in combination with the hydrographic survey points (see Fig. 6) to generate the 3D bed surface of the study area for the year 2012. Additionally, these points were merged with the derived levels points from the available topographic maps of the year 1944 and the year 1949 to generate the 3D bed surface profile before AHD construction (for the year 1964).

4.2 Prediction of the 3D Bed Surfaces

To predict the original reservoir 3D bed surfaces for years 1964 and 2012, the levels points data combined with the points that represent the water surface areas which derived from Landsat satellite images (as mentioned above in Sect. 4.1) are used in the interpolation process for the 2 years. The interpolation process is performed with the Radial Base functions (RBF) method [18].

4.3 Studying the Dead Zone Capacity

Studying the dead zone capacity (under level 147 m) includes the estimation of the annual and total amount of sediments in this zone and the computation of the approximate lifetime span of this zone.

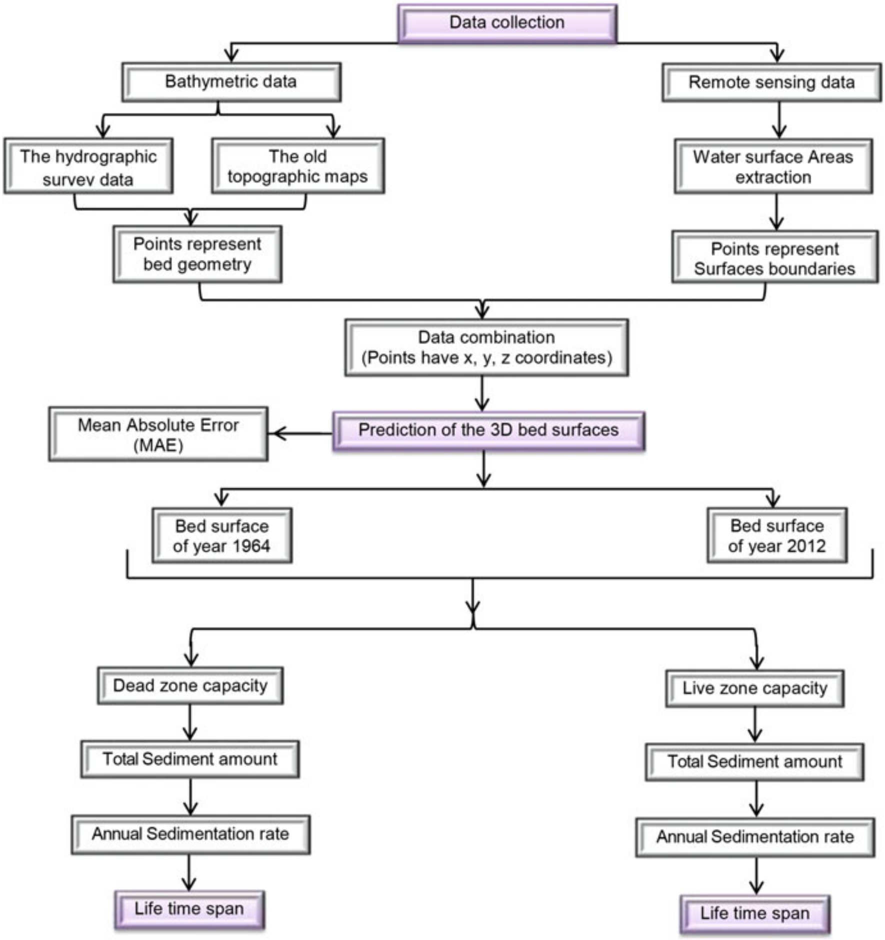

Fig. 5 The flowchart of the procedures involved in this study to estimate the LTS of AHDR

4.4 Studying the Live Zone Capacity

Studying the live zone capacity (between level 147 and 175 m) includes the estimation of the annual and total amount of sediments in this zone and the computation of the approximate the lifetime span of this zone.

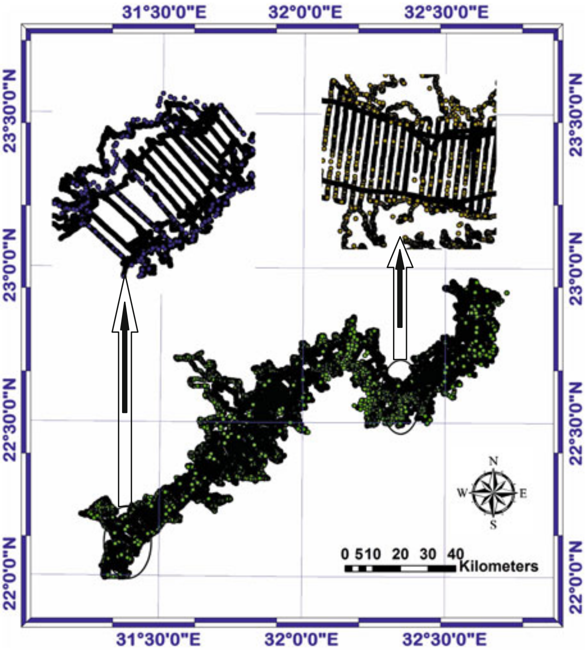

Fig. 6 The hydrographic survey points in combination with the water surfaces points

5 Results

Section 5.1 presents the results for the first part of AHDL (Lake Nasser) while Sect. 5.2 presents the results for the second part (Lake Nubia).

5.1 Results for Lake Nasser

5.1.1 Creation of the 3D Bed Profiles

The 3D bed surface of Lake Nasser was produced by using the extracted water surfaces generated by using the unsupervised technique from the available Landsat images of Lake Nasser. The Radial Base functions (RBF) method for interpolation is applied [18]. The RBF produce an acceptable value for the Mean Absolute Error (MAE) of 0.31 for the year 2012 indicating good accuracy of the interpolation process. The 3D bed surfaces were predicted for the years 1964 (before dam construction) and 2012 using ArcGIS software.

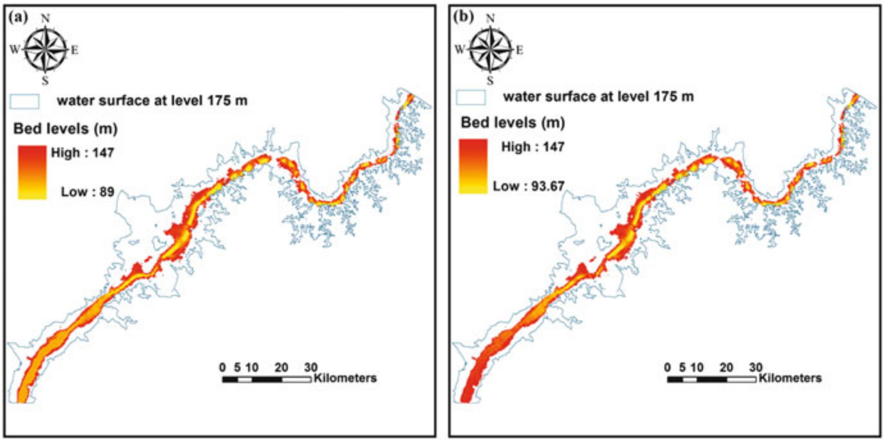

Fig. 7 The Predicted bed surfaces of Lake Nasser dead zone: (**a**) 1964 bed surface and (**b**) 2012 bed surface

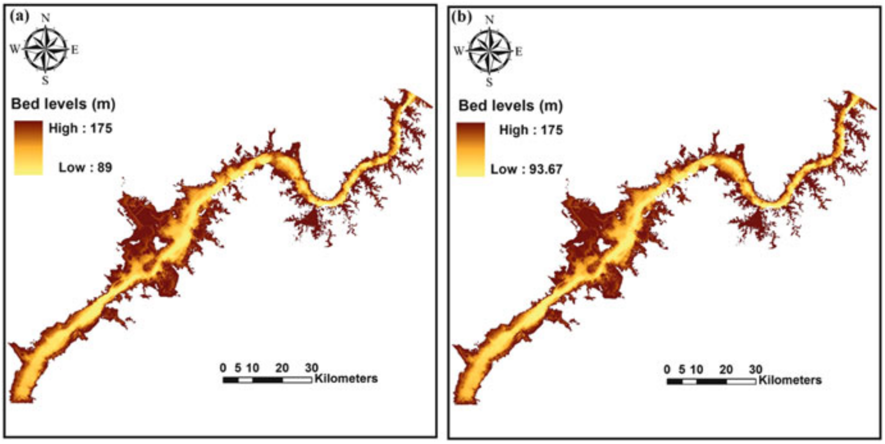

Fig. 8 The predicted bed surfaces of Lake Nasser up to its live zone maximum level: (**a**) 1964 bed surface and (**b**) 2012 bed surface

Dead Zone Bed Surfaces

The bed surfaces of Lake Nasser dead zone for the years 1964 and 2012 are created and presented in Fig. 7.

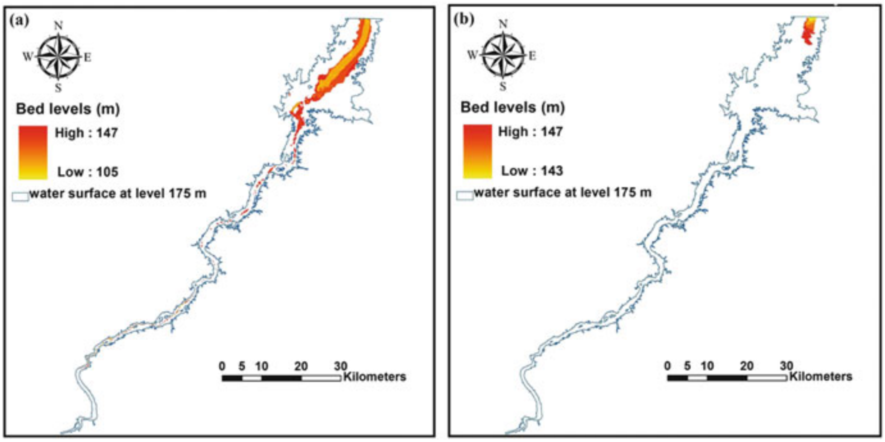

Fig. 9 The predicted bed surfaces of Lake Nubia dead zone: (**a**) 1964 bed surface and (**b**) 2012 bed surface

Live Zone Bed Surfaces

The 3D bed surfaces are predicted for Lake Nasser up to the high surface of its live zone. The results are presented in Fig. 8 for the years 1964 and 2012.

5.2 *Results for Lake Nubia*

5.2.1 Creation of the 3D Bed Profiles

Similarly, the 3D bed surfaces of years 1964 and 2012 are predicted for Lake Nubia using ArcGIS software. The extracted water surfaces by the unsupervised technique from all available Landsat images (remote sensing data) for Lake Nubia are used in the interpolation process. To obtain the complete predicted bed surfaces profiles of the lake by the interpolation process, the Radial Base function (RBF) method for interpolation is used. The RBF is accurate enough to interpolate the bed surface. Typically, the computed MAE for the year 2012 equals 0.22 indicating an acceptable accuracy of the interpolation process.

Dead Zone Bed Surfaces

Figure 9 shows the predicted bed surfaces of Lake Nubia dead zone for the year 1964 and the year 2012.

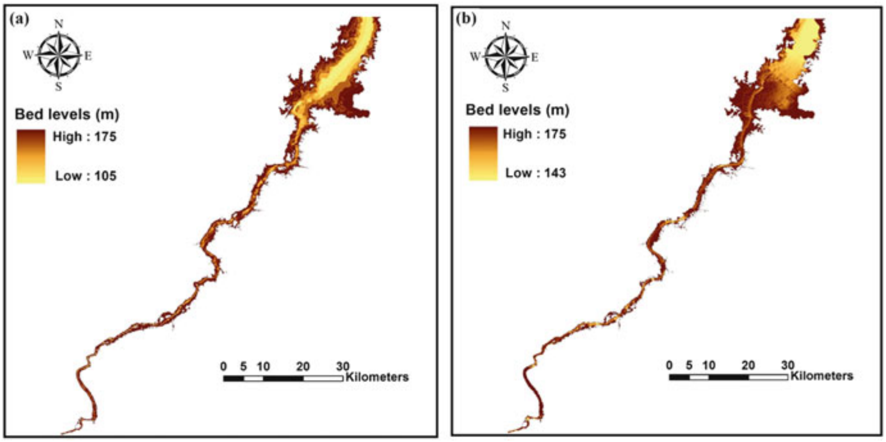

Fig. 10 The predicted bed surfaces of Lake Nubia up to the high surface of its live zone: (**a**) 1964 bed surface and (**b**) 2012 bed surface

Live Zone Bed Surfaces

The 3D bed surfaces are created for Lake Nubia up to the maximum level of its live zone. Figure 10 illustrates the results for the years 1964 and 2012.

6 Discussions

Section 6.1 presents the discussions for the first part of AHDR (Lake Nasser) while Sect. 6.2 presents the discussions for the second part (Lake Nubia).

6.1 Discussions for Lake Nasser

6.1.1 Sedimentation in Dead Zone

The total amount of sediment in the dead zone of Lake Nasser is estimated via the present approach (RS/GIS techniques) and the traditional method (cross-sections method) in order to estimate the annual sedimentation rate in this zone.

The annual mean sedimentation rate ΔS (m^3/yr) (Eq. 1) [19] was calculated for the period from the year 1964 to the year 2012.

Table 3 The computed sediment amounts and rates in the two studied parts from AHDR in the period (1964–2012)

The study part of AHDL			Total amount of sediment (B m^3)	Annual sedimentation rate (M m^3/yr)
Lake Nasser	DZ	The RS/GIS approach	1.165	24.27
		The traditional method	1.142	23.79
	LZ	The RS/GIS approach	0.029	0.60
		The traditional method	0.024	0.50
Lake Nubia	DZ	The RS/GIS approach	1.979	41.22
		The traditional method	1.970	41.04
	LZ	The RS/GIS approach	3.898	81.20
		The traditional method	3.893	81.11

$$\Delta S = \Delta V / \Delta t \quad (1)$$

where ΔV (m^3) is the total estimated amount of sediment in the period from 1964 to 2012; and Δt (yr) is the studied period (different between the two studied years).

The Present Method (RS/GIS Approach)

The sediment amount in the dead zone of Lake Nasser is computed from the created two bed surfaces shown in Fig. 7. This computation is performed using spatial and 3D analyst tools in ArcGIS software. The computed sediment amount in this zone is given in Table 3 which also shows the annual sedimentation rate.

The Traditional Method

The accumulated sediment volume in Lake Nasser dead zone is estimated from the year 1964–2012 [12]. Table 3 indicates the sediment amount and the annual sedimentation rate in Lake Nasser dead zone according to the tradition method (AHDA method).

6.1.2 Sedimentation in Live Zone

The total amount of sediment in the live zone of Lake Nasser is computed using the present approach and the traditional method in order to compute the annual sedimentation rate in this zone. The annual mean sedimentation rate in this zone is estimated using Eq. 1.

The Present Method (RS/GIS Approach)

According to the results shown in Fig. 8 and the computed amount of sediment in the dead zone, the total amount of sediment in the live zone of Lake Nasser is computed using spatial and 3D analyst tools in ArcGIS software. The computed result is shown in Table 3, which also shows the annual sedimentation rate.

The Cross-Section (Traditional) Method

The accumulated sediment volume in Lake Nasser live zone is estimated from the year 1964 to the year 2012 [12]. Table 3 illustrates the sediment amount and the annual sedimentation rate in this zone according to the tradition method.

6.2 Discussions for Lake Nubia

6.2.1 Sedimentation in Dead Zone

The total amount of sediment in the dead zone of Lake Nubia is computed using the present approach (RS/GIS techniques) and the traditional method in order to estimate the annual sedimentation rate in this zone. The annual mean sedimentation rate is estimated between years 2012 and 1964 by Eq. 1.

The Present Method

The sediment amount in Lake Nubia dead zone is estimated from the created two bed surfaces shown in Fig. 9. This estimation was performed by the spatial and the 3D analyst tools in ArcGIS software. The estimated amount is given in Table 3 which also shows the annual sedimentation rate.

The Cross-Section (Traditional) Method

The accumulated sediment volume in the dead zone of Lake Nubia is computed in the period (1964–2012) [12]. Table 3 shows the sediment amount and the annual sedimentation rate in this zone according to the cross-section method adopted by AHDA.

6.2.2 Sedimentation in Live Zone

The total amount of sediment in the live zone of Lake Nubia is estimated using the RS/GIS techniques and the traditional method in order to estimate the annual sedimentation rate in this zone. The annual mean sedimentation rate in this zone is estimated using Eq. 1.

The RS/GIS Approach

According to the results shown in Fig. 10 and the computed amount of sediment in the dead zone of Lake Nubia, the total amount of sediment in the live zone of this reservoir is estimated using spatial and 3D analyst tools in ArcGIS software. The computed result is presented in Table 3, which also shows the annual sedimentation rate.

The Cross-Section (Traditional) Method

The accumulated sediment amount in Lake Nubia live zone is estimated from the year 1964 to the year 2012 [12]. Table 3 indicates the sediment volume and the annual sedimentation rate in this zone according to this method.

According to the computed amounts of sediment in the various storage zones of AHDR as summarized in Table 3, it is obvious that the sediment was accumulated and distributed in Lake Nubia with an approximate proportion of 1:2 in its dead and live storage zones, respectively. On the other hand, most of Lake Nasser sediment was accumulated and distributed in its dead storage zone in the studied period from the beginning of water storing and formation of the AHDR in the year 1964 to the year 2012. This means that insignificant amount of sediment was accumulated and distributed in the live zone of Lake Nasser compared with that in the dead zone till year 2012.

Table 4 Sediment information for the dead and live zones of entire AHDR using RS/GIS approach

The storage zones characteristics	Dead zone (DZ)	Live zone (LZ)
Annual sedimentation rate in Lake Nasser (M m^3/yr)	24.27	0.60
Annual sedimentation rate in Lake Nubia (M m^3/yr)	41.22	81.20
Total (Lake Nasser + Lake Nubia)	65.49	81.80
Total annual sedimentation rate (M m^3/yr) for (DZ + LZ)	147.29	
Designed (maximum) storage capacity (M m^3)	31.6×10^3	90.7×10^3
Approximate lifetime span (yr)	482	830

6.3 Lifetime Span of AHDL

The computed annual sedimentation rates in the dead and live zones for both Lake Nasser and Lake Nubia by the RS/GIS approach and the traditional method are used to determine the LTS for these storage zones of AHDR.

The time span Ts (yr) of the AHDR dead and live zones is computed using Eq. 2 [19].

$$\mathrm{Ts} = V/\Delta S \tag{2}$$

where V (m^3) is the designed storage capacity of the dead and live zones (see Sect. 2); and Δs (m^3/yr) is the annual sediment rate.

6.3.1 The Present Method (RS/GIS Approach)

Based on the computed annual sedimentation rates in the various storage zones of AHDR, the expected LTS of each zone is calculated and the results for both Lake Nasser and Lake Nubia are summarized in Table 4.

As shown from Table 4, the approximate lifetime span of the dead zone of AHDR is about 482 years, while the approximate lifetime span of the live zone of this reservoir is about 830 years. Moreover, according to the computed lifetime span of these storage zones, the efficiency of the dead and live storage zones will be decreased by 20.75% and 12.05%, respectively, every 100 years of operation of the AHD. This rate will be changed after the operation of the Grand Ethiopian Renaissance Dam (GERD).

6.3.2 The Traditional Method

The results of the traditional method for both Lake Nasser and Lake Nubia [12] are presented in Table 5.

Table 5 Sediment information for dead and live zones of entire AHDL using the traditional method

The storage zones characteristics	Dead zone (DZ)	Live zone (LZ)
Annual sedimentation rate in Lake Nasser (M m^3/yr)	23.79	0.50
Annual sedimentation rate in Lake Nubia (M m^3/yr)	41.04	81.11
Total (Lake Nasser + Lake Nubia)	64.83	81.61
Total annual sedimentation rate (M m^3/yr) for (DZ + LZ)	146.44	
Designed (maximum) storage capacity (M m^3)	31.6×10^3	90.7×10^3
Approximate lifetime span (yr)	487	835

Table 6 The estimated annual reduction rate in the AHDR storage zones using the present approach and the method of sections

The storage zone	Annual reduction rate by RS/GIS approach (%)	Annual reduction rate by AHDA method
Dead storage zone	0.208	0.205
Live storage zone	0.121	0.120

As indicated in Table 5, the approximate lifetime span of the dead zone of AHDL is about 487 years, while the approximate lifetime span of the live zone of this reservoir is about 835 years according to the method adopted by AHDA.

6.4 Comparisons

Finally, both the present and the traditional methods are compared, based on the computed annual reduction rates in the dead and live storage zones for both Lake Nasser and Lake Nubia and the comparison is presented in Table 6.

Tables 4 and 5 illustrate that the present approach underestimates the lifetime span of dead and live zones of AHDL by about 1.03% and 0.60%, respectively, compared to the method used by AHDA.

Moreover, according to Table 6, it is clear that there was a slight difference in the computed annual reduction rate in the storage capacity zones of AHDR by both of the two methods (present and cross-section method). This means that the results of the present study and the AHDA approach are very close. Moreover, the computations of the LTS for dead and live storage zones using numerical simulations were 254 years and 964 years, respectively, based on Negm et al. [7]. In fact the 254 years was computed based on the total rate of sedimentation. If the sedimentation rate in the dead zone is used in calculations, it comes 546 years. It deviates by 13% and 12% compared to the present approach and the cross-section method, respectively. On the other hand, the LTS of live storage deviates by about 16% and 15.5% from the present approach and the cross-section method, respectively.

7 Conclusions and Recommendations

In the present study, the rate of sedimentation and lifetime span of the live and dead storage zones of AHDR are estimated using RS/GIS techniques.

For the first part of AHDR (Lake Nasser), the results illustrated that the annual rate of the deposited sediment in this part of AHDR is 24.27×10^6 m^3/yr for the dead storage zone and 0.60×10^6 m^3/yr for the live storage zone. For the second part of AHDR (Lake Nubia), the results indicated that the annual sediment deposition rate in this part is 41.22×10^6 and 81.2×10^6 m^3/yr for dead and live storage zones, respectively. Consequently, for the entire AHDR, the annual rate of sedimentation in its dead and live storage zones is 65.49×10^6 and 81.8×10^6 m^3/yr, respectively. Furthermore, the results indicated that the value of LTS of the dead zone is 482 years while the value of LTS of the live zone is 830 years. The RS/GIS approach underestimated the lifetime span of both dead and live zones of AHDL by about 1.03% and 0.6%, respectively, compared to the results of the method used by AHDA.

Finally, regular bathymetric surveys, continuous monitoring of sediment accumulation, and water capacity loss in AHDR are recommended during the next few decades to investigate the impacts of GERD to improve the economic feasibility and sustainability of this reservoir.

References

1. Garg V, Jothiprakash V (2008) Estimation of useful life of a reservoir using sediment trap efficiency. J Spatial Hydrol 8:1–14
2. Issa IE, Al-Ansari N, Knutsson S (2014) Mosul dam reservoir sedimentation characteristics, Iraq. J Environ Hydrol 22(3):1–10
3. Bhavsar MM, Gohil KB (2015) Review on study of reservoir sedimentation by remote sensing technique. Int J Innovative Res Sci Technol 1(12):251–254. ISSN: 2349-6010
4. Ahmed AA, Ahmed UH (2008) Sediment in the Nile River system. UNESCO-IHP-International Sediment Initiative
5. EL-Sersawy H, Farid MS (2005) Overview of sediment transport evaluation and monitoring in the Nile Basin. In: Ninth international water technology conference, IWTC, Sharm El-Sheikh, Egypt
6. Bhavsar M, Gohil KB, Shrimali NJ (2015) Estimation of reservoir capacity loss of Sukhi Reservoir by remote sensing. Int J Adv Res Eng Sci Manag 1(8). ISSN: 2394–1766
7. Negm AM, Abdel-aziz TM, Nassar M, Fathy I (2017) Estimating the life time span of Aswan High Dam Reservoir using numerical simulation of Nubia Lake. The Nile River, Hdb Env Chem. Doi: 10.1007/698_2017_2, © Springer International Publishing AG
8. Abdel-Aziz TM (1997) Prediction of bed profile in the longitudinal and transverse direction in Aswan High Dam Reservoir, PhD thesis, Faculty of Engineering, Cairo University, Giza, Egypt
9. Elsahabi MA, Negm AM, Ali KA (2016) Correlating the velocity profiles to the sediment profiles of the active sedimentation zone of Aswan High Dam Lake. In: Nineteenth international water technology conference, IWTC19, Sharm ElSheikh, Egypt

10. Mostafa MM, Soussa HK (2006) Monitoring of Lake Nasser using remote sensing and GIS techniques. ISPRS commission VII mid-term symposium remote sensing: from pixels to processes. Enschede, The Netherlands
11. Muala E, Mohamed Y, Duan Z, Zaag P (2014) Estimation of reservoir discharges from Lake Nasser and Roseires Reservoir in the Nile Basin using satellite altimetry and imagery data. Remote Sens (Basel) 6:7522–7545
12. NRI (2012) Nile Research Institute. Annual reports for studying sediment transport and water quality in Aswan High Dam reservoir (1973–2012). National Water Research Center, Cairo, Egypt
13. Elsahabi M, Negm AM, Ali K (2016) Performances evaluation of water body extraction techniques using Landsat ETM+ data: case-study of Lake Nubia, Sudan. Egypt Int J Eng Sci Technol 19(2):275–281
14. United States Geological Survey (USGS) U.S. Department of the Interior U.S. Geological Survey (USGS Earth Explorer): http://earthexplorer.usgs.gov/
15. MALR (2012) The Ministry of Agriculture and Land Reclamation, Egypt, the General Authority for AHDL Development, AHDL levels (1978 to 2012)
16. Elsahabi M, Negm A, El Tahan MH (2016) Performances evaluation of surface water areas extraction techniques using Landsat ETM+ data: case study Aswan high dam Lake (AHDL). Procedia Technol 22:1205–1212
17. Elsahabi M, Negm A, Ali K (2016) Investigating sediment and velocity distribution profiles for Nubia Lake using RS/GIS and field data. Procedia Eng 154:291–298
18. ESRI (2008) Environmental Systems Research Institute, Help topics of ArcGIS version 9.3 Desktop. Developer center of geographic information systems (GIS) software, Redlands, CA
19. Holanda PS, Blanco CC, Lopes DF, Secretan Y (2011) Hydrodynamic modeling and morphological analysis of Lake Água Preta: one of the water sources of Belém-PA-Brazil. J Braz Soc Mech Sci Eng. XXXIII(2):117–124

Estimating the Sediment and Water Capacity in the Aswan High Dam Lake Using Remote Sensing and GIS Techniques

Abdelazim Negm, Mohamed Elsahabi, and Sommer Abdel-Fattah

Abstract Egypt's Ministry of Water Resources and Irrigation (MWRI) is responsible for monitoring the changes in the Aswan High Dam Lake's (AHDL) capacity, which is of special importance after the construction of the Grand Ethiopian Renaissance Dam (GERD). The AHDL capacity is affected directly by the changes in the lake's bed surface. Thus, it is of the utmost importance for Egypt to properly understand these changes (sedimentation and erosion), to monitor the decrease in the storage capacity of the lake. Consequently, the main focus of this paper is to detect the changes in AHDL bed surface (practically sediment accumulation) during the period 2000–2012 using remote sensing (RS) and Geographic Information Systems (GIS) techniques by building a 3D profile of the lake. Moreover, this study is concerned with developing relationships between water volume or capacity/surface area/water level for the active sedimentation zone of AHDL for the years from 2000 to 2012; both individually and collectively. These relationships are estimated by establishing the developed rating curves (volume/level) and (area/level). The present computations are compared by the method of cross sections that was adopted by the Aswan High Dam Authority (AHDA) to detect the amount of sedimentation in the study area. The results indicate that the present approach

The original version of this chapter was revised: The text and reference corrections were updated. The erratum to this chapter is available at DOI 10.1007/698_2017_20.

A. Negm (✉)
Water and Water Structures Engineering Department, Faculty of Engineering, Zagazig University, Zagazig 44519, Egypt
e-mail: amnegm85@yahoo.com; amnegm@zu.edu.eg

M. Elsahabi
Civil Engineering Department, Faculty of Engineering, Aswan University, Aswan, Egypt
e-mail: mohamed.sahabi@aswu.edu.eg

S. Abdel-Fattah
McMaster University, Hamilton, ON, Canada
e-mail: abdelfs@mcmaster.ca

A.M. Negm (ed.), *The Nile River*,
Hdb Env Chem (2017) 56: 79–104, DOI 10.1007/698_2016_109,

overestimates the sedimentation capacity by about 4.3% compared to the results of the method used by AHDA. The measured velocity patterns are mapped, analyzed, and 2-D profiles are correlated to the erosion and sedimentation patterns. Moreover, the accuracy of the developed relationships is assessed by comparing the results with the observed data and the existing rating curves for the lake. The root mean square error is found to range between 5–10% and 2–4% for (a) the relationship between the lake capacity and the level, and (b) the lake surface area and the level relationship, respectively.

Keywords Aswan High Dam Lake, GIS, Lake capacity, Nubia Lake, Rating curve, Remote sensing, Sudan

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1 Introduction

Large reservoirs are used for many purposes, which include flood control, water storage for irrigation, generation of electricity, industrial or domestic use, and regulation of flow for navigation. Many man-made reservoirs have been constructed all over the world; among those are the Volta reservoir [1], Ghana, Lake Kainji on River Niger [1], Lake Kariba on Zambia River, Zambia [1, 2], Bratsk reservoir on Anga River, Russia [3, 4], Williston Lake on the Peace River, Canada, Zeya reservoir on the Zeya River in Russia [5], Lake Guri in Venezuela [6], and the Aswan High Dam Lake (AHDL) on the River Nile in Egypt [1] and through Sudan.

The High Dam differs from other dams in a number of characteristics. It is the biggest rockfill dam in the world. It has an impervious core, with a grout curtain that extends 180 m under the core to meet the rock, and a horizontal upstream impervious blanket. The length of the dam at the top is 3,600 m, while the width is 980 m at the bottom and 40 m at the top and its height above the river bed level is 111 m.

Before the construction of Aswan High Dam (AHD), around 125 million tons of mud was transported annually through flooding. The sedimentation consists of fine sand, silt, and clay, which contributes to soil fertility. About 15% of this mud has been deposited in irrigated areas of Upper Egypt and in the Nile bed upstream Cairo; roughly, the same amount or more was spread in the agricultural lands of the Nile Delta. Most of the mud quantity brought down to the Delta coast was deposited through the Rosetta and Damietta estuaries. The remaining amount of mud was deposited in the continental shelf at the Mediterranean Sea.

The situation has changed after the construction of the Aswan High Dam in 1964, and the formation of a large reservoir, named the High Dam Lake (Nasser/ Nubia). This was largely due to the increasing rate of mud storage in the dead zone in Nasser Lake and the lesser chance for mud to travel in the River Nile through its journey to Mediterranean Sea.

Since sedimentation in this lake is dominant, the problem arises that storage capacity is decreasing over the years yielding the reservoir useless after some decades [7]. Adding to the above, it was found that the storage of mud in the dead zone caused the formation of a new delta in the lake inside the Sudanese region (Nubia Lake). This formation of a new delta will decrease the life of the reservoir since the volume of storage in the dead zone is about 31.6 billion cubic meters, and the life of reservoir is defined by scientists as the time required for sediment to fully fill the dead zone of the lake. This sedimentation can in turn adversely affect the working turbines and operation of the High Dam. The trapping of sediment by the dam has been the reason for the increase of coastline erosion surrounding the River Nile Delta.

Based on the above discussion, it is necessary to carry out a study to estimate the amount of sediment in the AHDL, and to optimize the utilization of this sediment accurately in order to manage its removal in a better, more efficient, and economic manner. The trapped sediment can be used effectively in many fields to gain an optimum benefit, such as increasing the soil fertility by spreading the lake sediment over desert lands, contributing to duplicating the production of the land, and decreasing the risk on the Aswan High Dam.

The AHDL is vital to Egypt; as it stores and regulates Nile water; the main source of fresh water for about 85% of its population [8]. Therefore, it is of the utmost importance for Egypt to understand properly the changes which occur in the AHDL bed surface (the morphological changes related to erosion/sedimentation processes). This will help in monitoring the variation in the storage capacity of the lake, improving the knowledge on the water mass balance, and consequently enabling this lake to fulfill its purpose efficiently [9].

Many studies have been carried out on the Lake as well as changes in progress over time. Many of these studies were issued in the form of reports, papers, books, dissertations, as well as seminars and workshops. Most of these publications, especially reports, dissertations, seminars, and workshops, are either of limited distribution or unavailable to research workers. The authors tried to obtain these studies in the present work. In situ measurements and satellite observations data have been used to estimate and analyze changes in lake bed surfaces, with successful applications in different parts of the world. An example includes the morphological changes related to erosion and sedimentation processes which occurred in San Giuliano Lake which is located in the Basilicata Region (Southern Italy). This phenomenon was examined during the period 1984–2004, and was analyzed using RS data integrated GIS technique [10]. Schultz [7] detected the changes in sediment and erosion in the upper region of Lake Kemnade in the Ruhr River valley in Germany using remote sensing techniques and echo sounding data for a period of 8 years. El-Sammany and El-Moustafa [11] proposed a method for calculating the changes in the AHDL bed from the year 1953 to the year 2004 depending on the processing of the field measurements (bathymetric data) only using GIS tools, such as geo-spatial analysis and 3D analysis tools in order to analyze the Digital Elevation Models (DEMs) for the study area. Negm et al. [12] studied the scouring and silting processes in the AHDR by applying a two-dimensional numerical model. Concerning the flow velocity characteristics and distribution in the AHDL to indicate its effect on sedimentation and erosion processes in the lake, limited research was conducted; these include [11, 13, 14]. Furthermore, many investigations estimating the water storage quantity and variations in lakes and reservoirs were carried out in other parts of the world, including: Roseires reservoir in Sudan [15], Lake La Bure in the south – west of France [16], Lake Izabal in Guatemala [17], Lake Tana in Ethiopia and Lake Mead (U.S.A) [18], Lake Dongting in China [19], and Randy Poynter Lake in Georgia [20]. Concerning the Aswan High Dam Lake (AHDL), several studies were conducted including those of [15, 21, 22].

The main aims of the present study are:

(a) detecting the changes in the AHDL active sedimentation of the bed surface (sediment and erosion) and the quantitative amounts from year 2000 to 2012 using GIS and RS techniques
(b) detecting the effect of inflow velocity on sediment and erosion patterns via the comparison between changes of the lake bed profiles and the corresponding 2-D inflow velocity profiles
(c) developing the rating curves for the Lake Nubia active zone for the period from 2000 to 2012 through a combination of remotely sensed data and in situ measurements, in order to detect the variations in the water capacity
(d) a comparison between the results of the method used by the Aswan High Dam Authority (AHDA) based on the complementary cross sections in estimating

the amounts of sediment, the water capacity in the study area and the results of the present study using RS/GIS.

It is hoped that the current study will contribute to the knowledge foundation of the AHDL and help those who are responsible for sustainable development, management, and protection in their decision making and planning.

2 Study Area and Data Collection

2.1 The Study Area

AHDL is considered one of the largest man-made lakes in Africa, and extends for 500 km south of the dam. The majority of this lake lies in Egypt with a length of about 350 km and is known as Lake Nasser. On the Sudanese side, it is referred to as Lake Nubia (LN) [23] with a length of 150 km. The study area extends between latitudes 21°44′30″ and 22°00′00″N (upstream AHD) within the Sudanese part (LN) where most of the sediments are accumulated. It contains six cross sections (22, 24, 25, 26, 27, and 28) from North to South as indicated in Fig. 1.

In addition, from the studies and observations done by field survey missions, which were successfully carried out through the joint efforts of the Aswan High Dam Authority (AHDA) and the Nile Research Institute (NRI), it was concluded that the cross sections have been enlarged due to excessive erosion and the water velocity has decreased in this portion [24]. The study area considers the lake portion with most intensive sediment deposition. Moreover, the total amount of the accumulated sediment in this part of the AHDL is about 50–70% of the total amount of sediment in the AHDL as indicated in the foregoing estimations by AHDA [24]; although this portion represents only about 5.96% of the total area of the AHDL [26]. This reach is called the active sedimentation portion.

The geometric characteristics of the AHDL (large area, high depth, and bed relief) make the detection of the lake bed surface changes and estimation of the lake volume difficult to be examined by traditional methods and therefore, need to be as accurate as possible for operational purposes by applying new techniques such as remote sensing and GIS.

2.2 In Situ Data

2.2.1 Hydrographic Survey Data

The hydrographic survey data, which is described by the geometry of the AHDL, were collected by using the eco-sounder via field trips performed by AHDA and NRI. The lake geometry presented by Easting, Northing, and Elevation

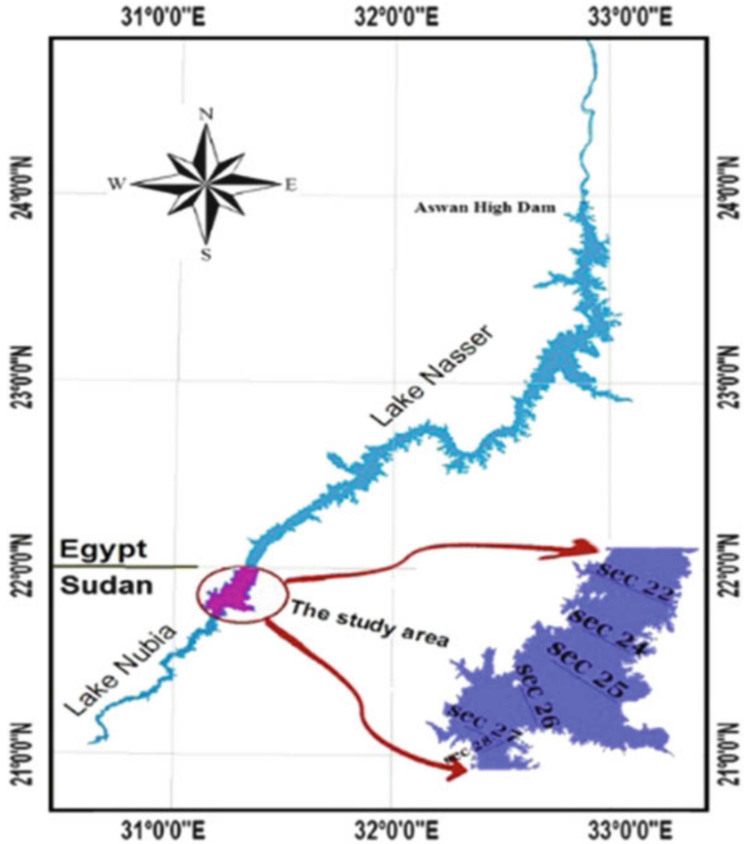

Fig. 1 Location of the study area in AHDL

(E, N, and Z) was used for the 3D bed surface generation. In this study, the hydrographic survey data for years 2000, 2004, 2006, 2008, 2010, and 2012 for the study area were used [24].

2.2.2 Water Levels Data

The water levels upstream AHD, which were recorded by AHDA gauge stations at different times of the year [25], were collected to help in detecting the water surface levels at the dates of acquiring the satellite images.

2.2.3 Inflow Velocity Data

The inflow velocity data, which represents the velocity magnitudes, were measured by using the Vale Port velocity meter device via the AHDA and NRI field trips.

These data were obtained at the locations of the cross sections shown in Fig. 1. In this study, the inflow velocity magnitudes data for the years 2006, 2008, and 2010 were used [24].

2.2.4 Inflow Quantity Data

The total amounts of discharge (inflow) which arrives at Aswan (enters Egypt) for the last 20 years, as recorded by AHDA and according to the Dongola gauge station [26], are used to detect the effect of this charge on the lake bed.

2.3 Satellite Images (Remote Sensing Data)

Three Landsat ETM+ images (Path/Row = 175/045) were used in this research. The three images were acquired on different dates (September 2000, March 2006, and March 2009) from the GLCF website in GeoTIFF (systematic correction) products [27]. The acquired images are used to extract the lake boundaries. The satellite images were taken in September 2000 when the water level of the lake was 178 m amsl; in March 2006 when the water level was 173 m, and in March 2009 when the water level was 176.60 m.

3 Methodology

To achieve the objective of the present work, the adopted methodology is provided in Fig. 2, and is explained in the following subsections.

3.1 Water Surface Areas Extraction

Many investigations of water area estimation have been carried out worldwide [29–33]. Considering the AHDL, many water surface extraction studies have been carried out on Lake Nasser [11, 15, 28], while few studies concentrated on Lake Nubia [11].

Remotely sensed imagery has many applications in water resource assessment and management. These applications involved the extraction of water information by various techniques [30].

In this study, the unsupervised classification technique of Landsat images to obtain the water body class of the AHDL was performed; it is considered the best technique for water texture recognition [8, 34].

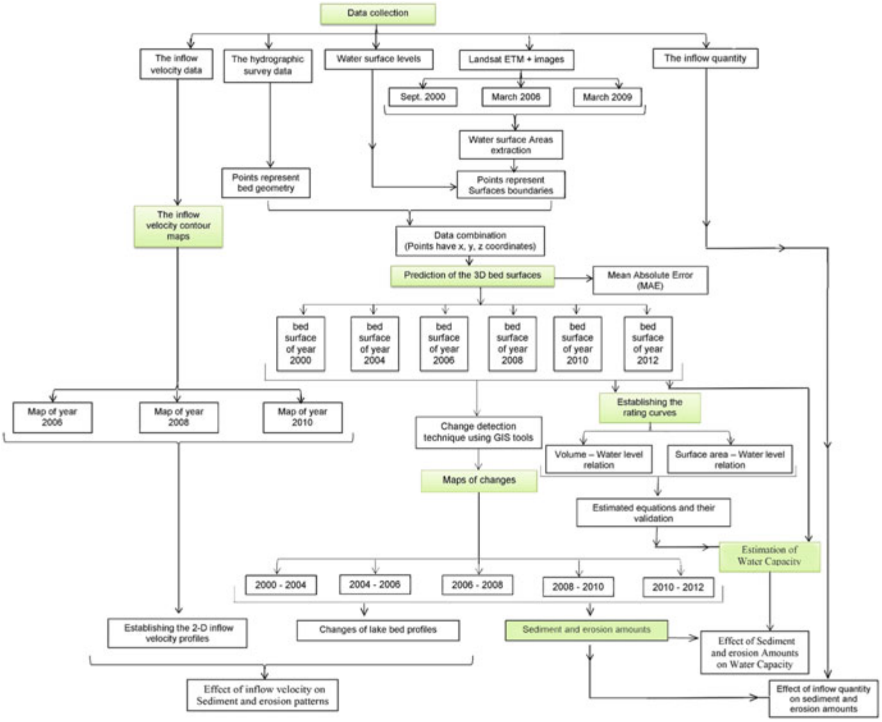

Fig. 2 Flowchart of the procedures adopted in this study to achieve its goals

The applied procedures for extraction of water boundaries in this study (using unsupervised image classification technique) are explained below and summarized in Fig. 3.

(1) Detecting the Landsat scene of the study area by making a clip from the original image.
(2) Making unsupervised classification, then converting the final classified image (contain four classes) into features (vector layers).
(3) Separating the water feature from the other features as a polyline.
(4) Converting the polyline boundaries into a water points layer which has (x, y) coordinates and z coordinates from the water levels recorded by the AHDA which were synchronized with the acquired dates of the satellite images.
(5) Converting the water polyline layer into polygon layer.
(6) Finally, converting the polygon layer to raster water scene (water raster) to help in the interpolation method (predicting the 3D bed surface).

The extracted lake boundaries, obtained from the satellite images, were used to form the shape of surface and also to form a group of scatter points (x, y, z) using the WGS84, UTM Z36N as defined in the projected coordinate system. These points were used, combined together with the hydrographic survey points in the generation

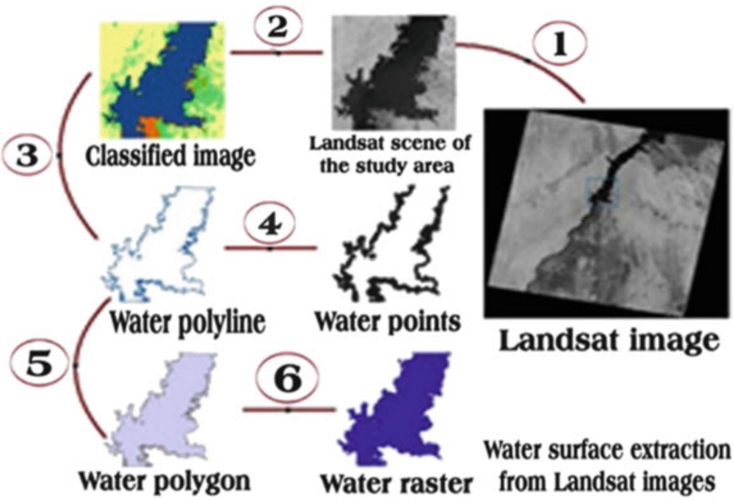

Fig. 3 Extraction of water boundaries from Landsat images

of the 3D bed surfaces of the study area for all available years (2000, 2004, 2006, 2008, 2010, and 2012).

3.2 Prediction of the 3D Bed Surfaces

In order to predict the original lake 3D bed surfaces from the year 2000 to the year 2012, the available hydrographic survey data combined with the points that represent the water surface areas which were derived from Landsat satellite images were used in the interpolation process. In addition, the water surface, which represents the highest surface for all predicted bed surfaces, was from the 2000 Landsat image. The interpolation process is performed with the Radial Base Functions (RBF) method [35].

To assess the accuracy of the interpolation methods, the Mean Absolute Error (MAE) is estimated. For accurate interpolation, the MAE should be as close to zero as possible, as the error here represents the difference between measured and predicted values.

3.3 Change Detection Technique

This technique is a digital overlaying technique which depends on detecting the changes in the lake bed levels by overlaying every two sequential predicted bed surface images using the cut/fill tool in the ArcGIS Software [36].

3.4 Establishing Maps of Changes

The maps of changes were derived using the change detection technique and represent the changes in sediment and erosion zones. These maps were generated in order to quantify the changes in sediment and erosion in the study area during the period from 2000 to 2012.

3.5 Generation of the Inflow Velocity Contour Maps

In order to establish the inflow velocity contour maps for years 2006, 2008, and 2010, the available inflow velocity magnitude data were used in the interpolation process. This process was performed by using ArcGIS software. These contour maps were produced in order to explain the effect of the velocity magnitudes on erosion and sedimentation patterns [37].

3.6 Establishing the Rating Curves

The relationships between the three parameters of the lake (water volume/surface area/level changes) are estimated by using ArcGIS software v9.3 [35]. These relationships are generated in order to establish the rating curves for the years from 2000 to 2012.

3.7 Rating Curves Equations and Their Validation

The equations of the developed rating curves (volume/level), (area/level), and (volume/area) are estimated by using Microsoft Excel [38].

Table 1 presents the statistical indicators including Root Mean Square Error (RMSE) and R^2 (coefficient of determination) that are used to assess the accuracy of the developed rating curves equations.

Table 1 Statistics indicators for the equations of the developed rating curves [9]

Concept	Name	Formula
Root M. square error	RMSE	$\sqrt{\sum (\mathrm{Mes} - \mathrm{calc.})^2 / N}$
Deter. coefficient	R^2	$\sum(\mathrm{calc.} - \mathrm{avg.Mes})^2 / \sum(\mathrm{Mes} - \mathrm{avg.Mes})^2$
Percent. of root M. square error	RMSE (%)	$(\mathrm{RMSE}/\mathrm{avg.Mes}) \times 100$

4 Results

4.1 Creation of the 3D Bed Profiles

The extracted water surfaces built using the unsupervised technique from all available Landsat images (see Fig. 4) are used in the creation of the 3D bed surfaces.

In order to predict the 3D bed surfaces, the Radial Base Functions (RBF) method for interpolation is used as it produces good results for gently varying surfaces such as elevations [34].

To assess the accuracy of the used RBF method, MAE was computed and is found to be close to zero for all studied years. The MAE for year 2010 equals 0.003281 indicating a high level of accuracy of the interpolation process as shown in Fig. 5.

The 3D bed surfaces are predicted for the years 2000, 2004, 2006, 2008, 2010, and 2012. Sample results are presented in Fig. 6 for the years 2006 and 2008.

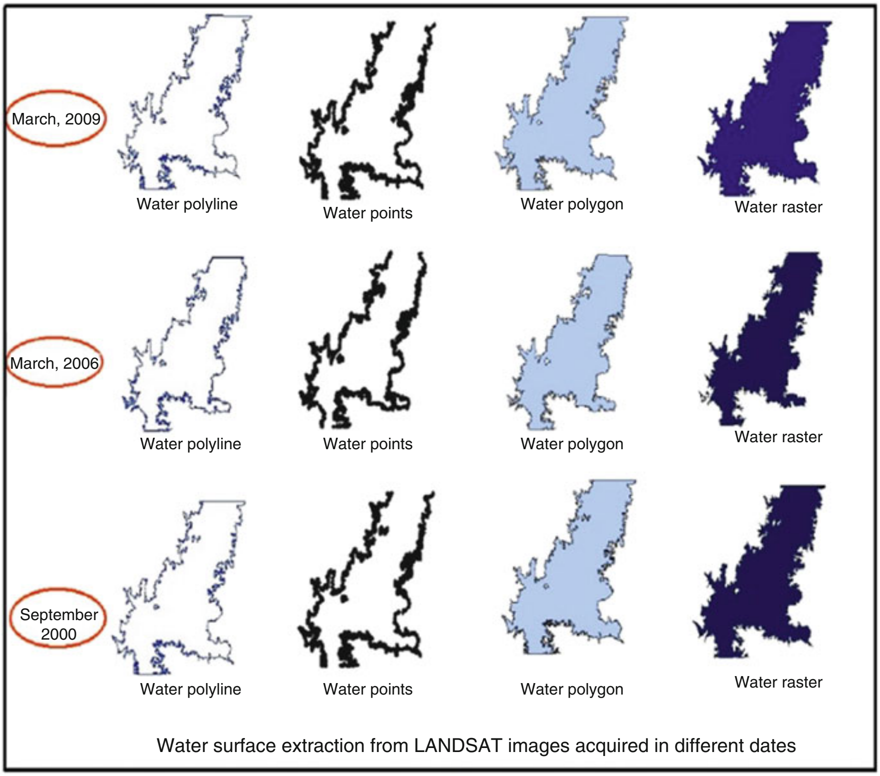

Fig. 4 The extracted water boundaries from Landsat images

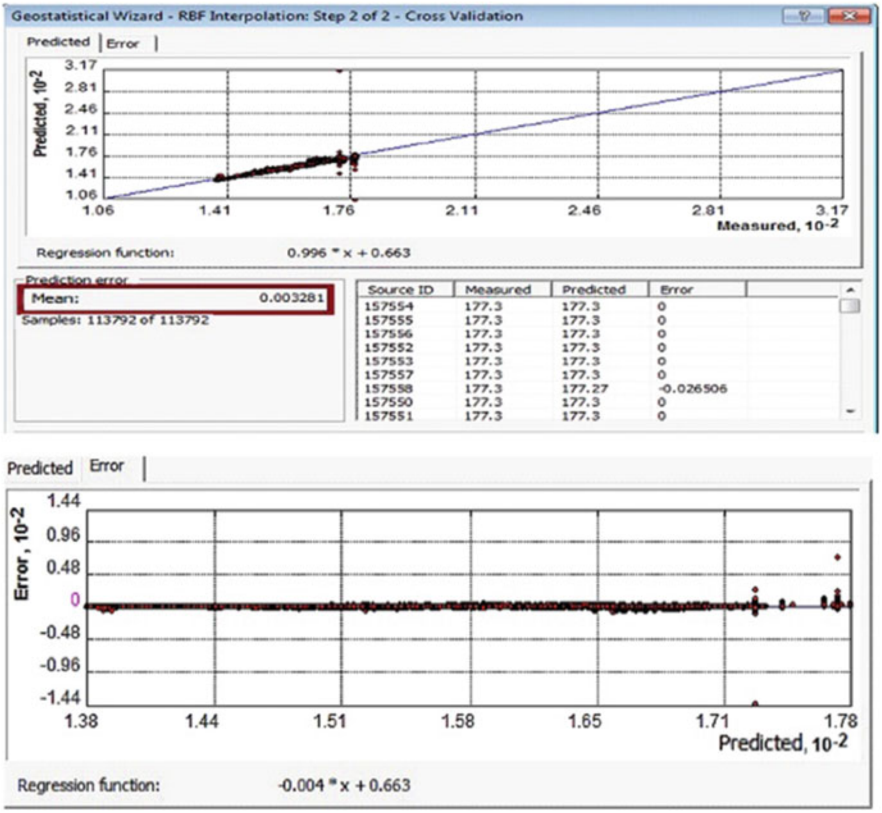

Fig. 5 Errors in the predicted values for year 2010

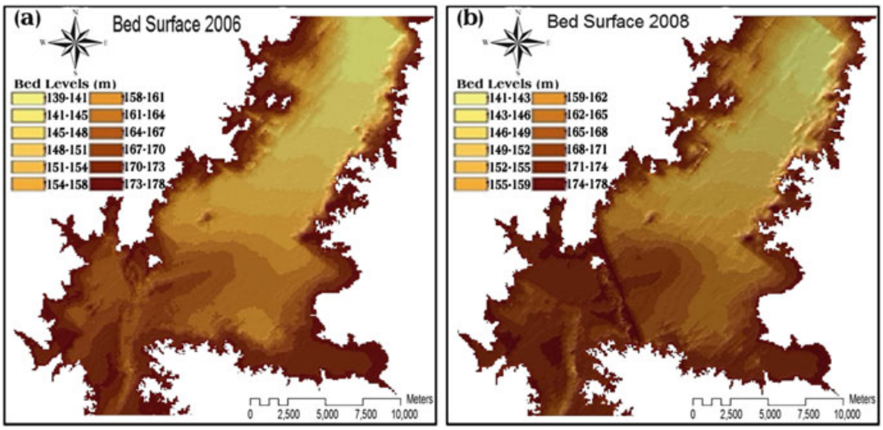

Fig. 6 Sample results of the predicted bed surfaces for the years (**a**) 2006 and (**b**) 2008

4.2 Maps of Changes

To infer the changes in bed levels between every two sequential predicted bed, surfaces were generalized by three broad change categories:

- No change: the levels that have the same values in both the old and new bed surface
- Sedimentation: the old bed surface levels were increased in the new bed surface
- Erosion: the old bed surface levels were decreased in the new bed surface

Maps of changes for the years 2004–2006, 2006–2008, and 2008–2010 are produced. Samples for the years 2006–2008 and 2008–2010 are presented in Fig. 7.

4.3 Velocity Maps

The collected field data about the inflow velocity values for years 2006, 2008, and 2010 were interpolated by using ArcGIS software. Afterwards, the velocity contour maps were produced.

Figure 8 shows sample results for years 2006 and 2010, respectively.

5 Discussion

5.1 Sediment and Erosion Changes

Figures 9 and 10 show the change in sediment and erosion amounts, respectively, from year 2000 to 2012, that were estimated by using the statistics of the change categories (classes) in the maps. It is obvious from these figures that there is an increase in the amount of sediment from the years 2000–2004, 2006–2008, and 2010–2012 accompanied with decrease in the amount of erosion in the same periods.

There is a decrease in the amount of sediment from year 2008 to 2010 accompanied with an increase in the amount of erosion in the same period. From the years 2004 to 2006, the amount of sediment is nearly equal to the amount of erosion.

Table 2 shows the change in sediment and erosion 2D surface areas, respectively, from the years 2000 to 2012; it is obvious from this table that the values of the 2D areas of sediment and erosion are approximately proportional to the amounts of sediment and erosion, as the amount of erosion increase leads to increase in its 2D area and vice versa, and the same manner for sedimentation.

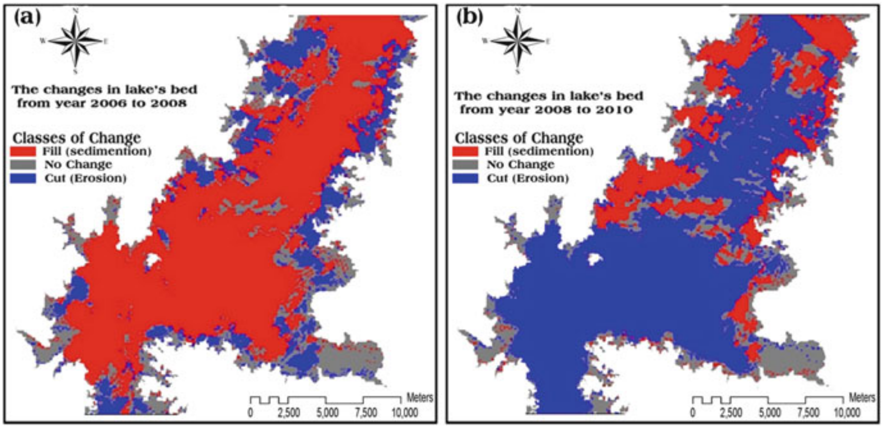

Fig. 7 Sample for maps of changes for the years 2006–2008 and 2008–2010

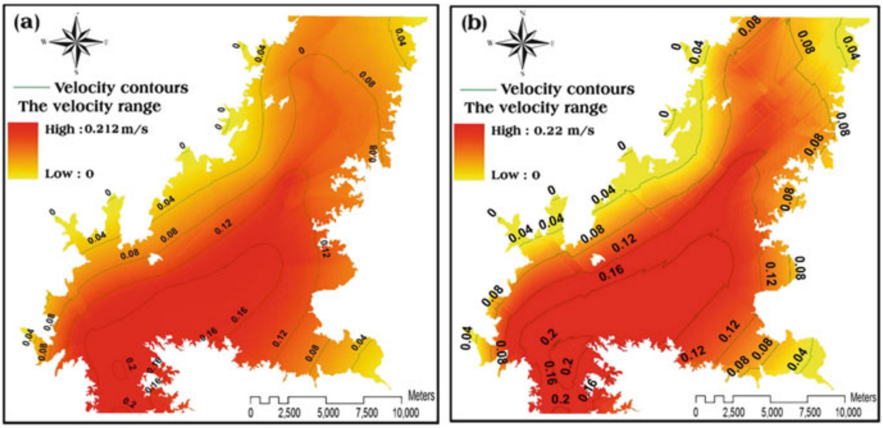

Fig. 8 Sample for the inflow velocity contour maps for the years 2006 and 2010

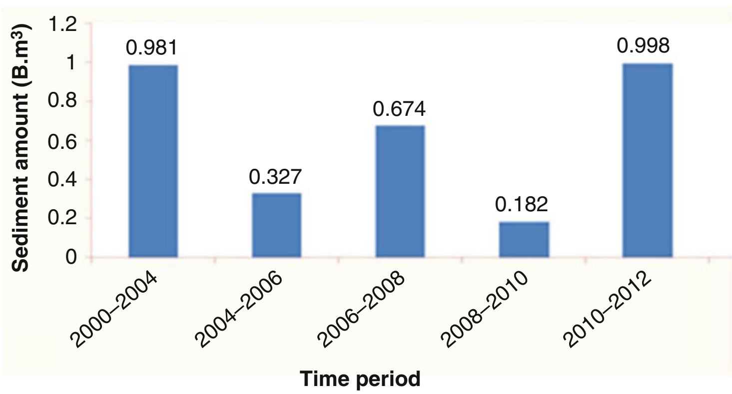

Fig. 9 Sediment amount in the study area

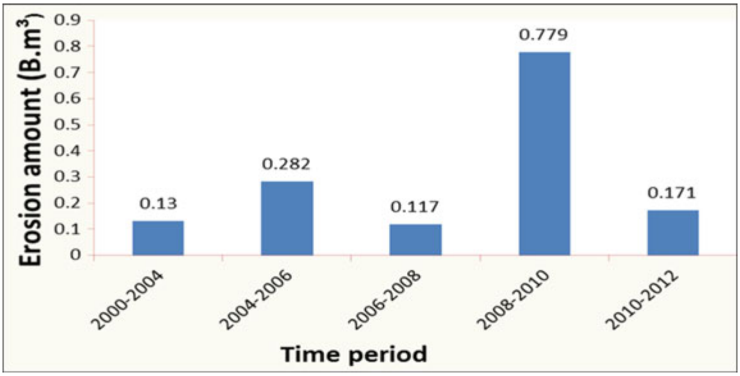

Fig. 10 Erosion amount in the study area

Table 2 2D surface area of sedimentation and erosion from year 2000 to 2012

Time period	2D area of sediment (km^2)	2D area of erosion (km^2)
2000–2004	227.45	47.06
2004–2006	145.70	91.38
2006–2008	216.05	48.84
2008–2010	59.93	205.81
2010–2012	222.28	50.19

5.2 *Effect of Inflow Quantity on Sediment and Erosion Amounts*

Table 3 shows the difference in the annual inflow quantity (discharge) in the study area, which is recorded at Aswan at the end of July [26]. By comparing this table with Fig. 8, we can realize that the amount of erosion is directly affected by the amounts of inflow, as a decrease in the inflow quantity leads to an increase in the amount of erosion and vice versa. This explains the change in the amount of erosion from the year 2000 to the year 2012. From Table 3 and Fig. 9, it is obvious that there is an increase in sedimentation amounts between the years 2000–2004, 2006–2008, and 2010–2012 due to the increase in the inflow amount. There is a decrease in sediment during the period 2008–2010 due to the decrease in inflow. In spite of this, a direct relationship between the sediment amount and the incoming flow to the lake cannot be detected, as sediment amount depends not only on the quantity of inflow but also on some other parameters such as the particles size of sediment, the inflow velocities, and shape and size of the lake's cross sections which are perpendicular to the incoming flow of the lake. Thus, it is recommended to study the effects of these parameters on the amount of sediment in future research.

Table 3 Quantity of inflow from 2000 to 2012

Year	Inflow (Bm^3)	Average (Bm^3)
2000–2001	69,512	59,678
2001–2002	70,878	
002–2003	41,794	
2003–2004	56,528	
2004–2005	47,287	50,403
2005–2006	53,518	
2006–2007	80,420	78,170
2007–2008	75,920	
2008–2009	55,130	48,635
2009–2010	42,139	
2010–2011	63,314	56,700
2011–2012	50,085	

5.3 *Effect of Inflow Velocity on Sediment and Erosion in the Lake Bed Surface*

Flowing water erodes or deposits particles depending mainly on how fast the water is moving. The following examples are considered as indicators on the effect of the inflow velocity values on the lake bed surface relief. These examples illustrate the relationships between (a) the 2-D velocity profiles and (b) the bed change profiles which are deduced from the predicted bed surfaces and the generated velocity contour maps, respectively.

The first example that illustrates the relationship between the inflow velocity and the changes of lake bed surfaces profiles is shown in Figs. 11 and 12, and indicates the bed surfaces cross sections at sections 22 and 26 (see Fig. 1) and the corresponding 2-D inflow velocity profiles. It can be noticed that the increment in the velocity rates is associated with decrement in bed surface levels (high amounts of erosion), as occurred during 2008–2010. On the other hand; the decrement in the velocity rates is accompanied with incremental changes in bed surface levels (high amounts of sedimentation), as occurred during 2006–2008.

The second example for indicating the effect of the inflow velocity magnitude on the sediment and erosion pattern is shown in Fig. 13, which illustrates the comparison between changes of the bed profiles (longitudinal sections that pass through the lowest points in the study area bed surface) and the corresponding 2-D inflow velocity profiles for the years; 2006, 2008, and 2010. The analysis of this figure confirmed the velocity effect on sedimentation and erosion patterns through the achieved comparisons in Figs. 11 and 12.

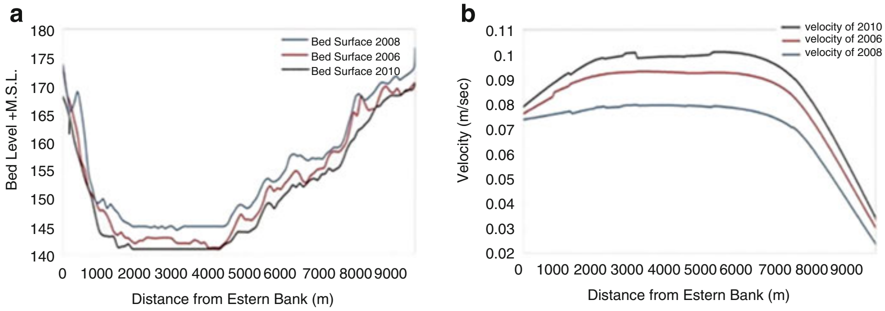

Fig. 11 Comparison between bed surfaces and velocity profiles at section 22 (337.5 km U.S AHD): (**a**) bed surfaces cross sections; (**b**) velocity distribution

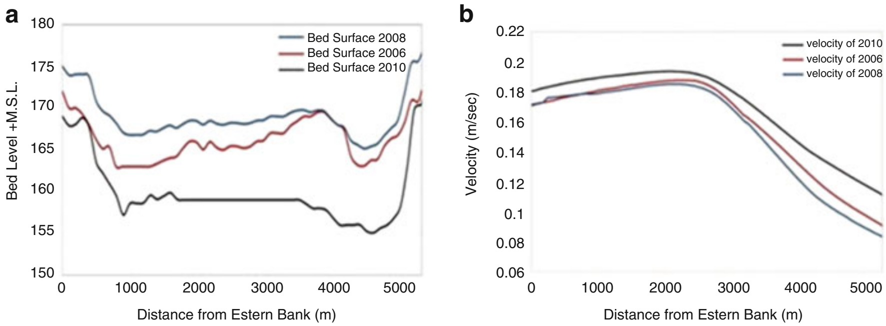

Fig. 12 Comparison between bed surfaces and 2-D velocity profiles at section 26 (357 km U.S AHD): (**a**) bed surfaces cross sections; (**b**) velocity distribution

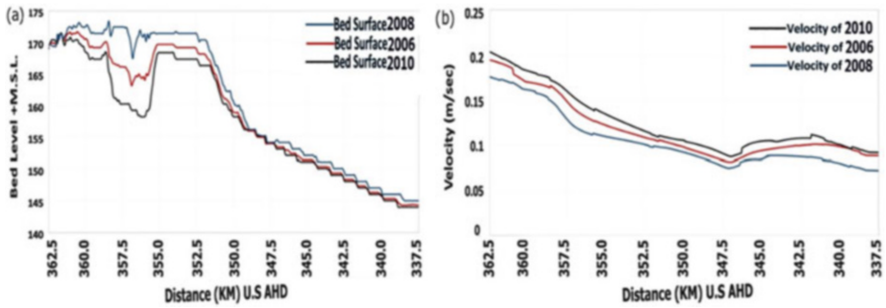

Fig. 13 Comparison between bed surfaces and 2-D velocity profiles: (**a**) bed surfaces longitudinal sections; (**b**) velocity distribution

5.4 Rating Curves and Their Validation

To infer the water capacity (volume) variations in the study area, we developed various rating curves between volume or capacity, surface area, level changes, which are closely connected with the lake remotely sensed data and hydrographic survey data.

5.4.1 Volume/Level Relation

Figure 14a, b shows samples of established rating curves that represent the relationships between volume/level for the year 2010 and collectively for the whole period from 2000 to 2012. It is noticed from these graphs that the volume changes as a function of level change and expressed a third polynomial relationship.

Table 4 presents the eight developed equations for the years (2000, 2004, 2006, 2008, 2010, and 2012), for 2 years (2010 and 2012), and for all years (2000–2012) for the relationship between volume/level. From this table it is clear that the computed volumes are in a good agreement with measured volumes with R^2 varied from 0.94 to 0.99 and RMSE varied from 5 to 10% only.

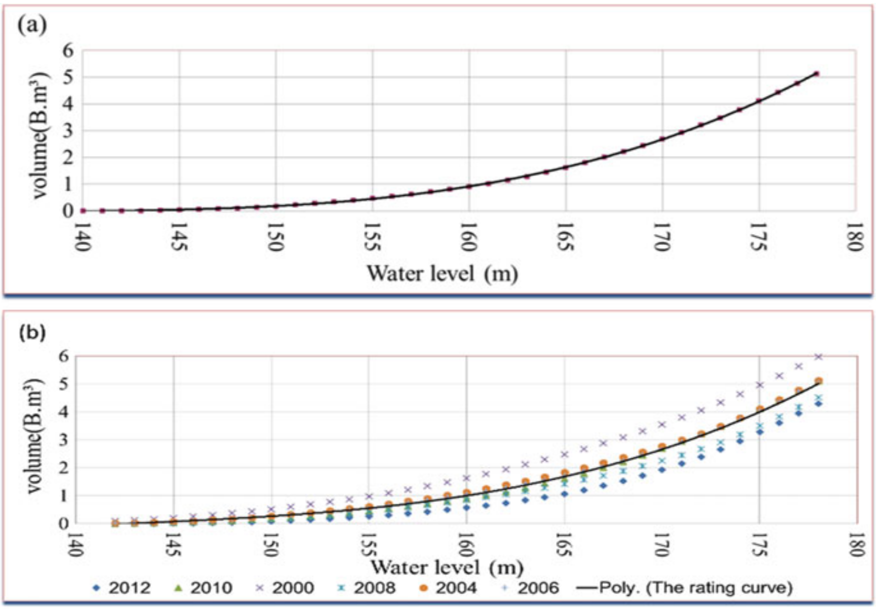

Fig. 14 Sample results of the rating curves (volume/level): (**a**) 2010 rating curve and (**b**) collective rating curve for the years (2000–2012)

Table 4 Developed relationships between volume and water depth for the period from 2000 to 2012, individually and collectively

Period of the estimated rating curve	Number of points	R^2	RMSE (Bm^3)	RMSE (%)	Rating curve equation (y = volume in Bm^3 and x = water level in m)
2000	45	0.99	0.091	5.2	$y = 4\,E-05\,x^3 - 0.0148\,x^2 + 1.817\,x - 74.04$
2004	40	0.99	0.084	5.6	$y = 7\,E-05\,x^3 - 0.0292\,x^2 + 4.0817\,x - 191.2$
2006	40	0.99	0.078	5.4	$y = 8\,E-05\,x^3 - 0.0337\,x^2 + 4.7562\,x - 224.92$
2008	38	0.99	0.070	5.5	$y = 9\,E-05\,x^3 - 0.0388\,x^2 + 5.6086\,x - 271.85$
2010	39	0.99	0.069	4.9	$y = 8\,E-05\,x^3 - 0.0332\,x^2 + 4.6016\,x - 213.06$
2012	37	0.99	0.058	5.3	$y = 0.0001\,x^3 - 0.0431\,x^2 + 6.1978\,x - 297.355$
2010 and 2012	74	0.97	0.099	7.6	$y = 0.0001\,x^3 - 0.043\,x^2 + 6.1793\,x - 296.7$
2000–2012	222	0.94	0.164	10.7	$y = 9\,E-05\,x^3 - 0.0386\,x^2 + 5.5358\,x - 265.35$

5.4.2 Area/Level Relation

The relationship between area/level is clearly nonlinear (a second-order polynomial function). A sample of the obtained results is presented in Fig. 15a, b for the years 2010 and for all years from 2010 to 2012.

Similarly, Table 5 presents the eight developed equations for the relationship between area and level for the active sedimentation zone of Lake Nubia for the years (2000, 2004, 2006, 2008, 2010, and 2012), (2010 and 2012) and collectively for the period from 2000 to 2012. The value of R^2 is more than 0.97 while RMSE ranged between 2.7 and 5.4 m. The predicted surface area values using the developed equations are compared with the measured values as shown in Fig. 16 for the lake water level of 175 m.

5.5 Water Capacity of the Study Area

As a quantitative indicator for the above results, Fig. 17a, b shows the difference between measured water capacities via the created 3D bed profiles and the calculated water volumes from the derived rating curve equations at water level 178 and 175 m, respectively. These figures illustrate that the computed and the measured volume values are nearly equal for individual studied years. In contrast, there is a difference in the volume values collectively for years from 2000 to 2012.

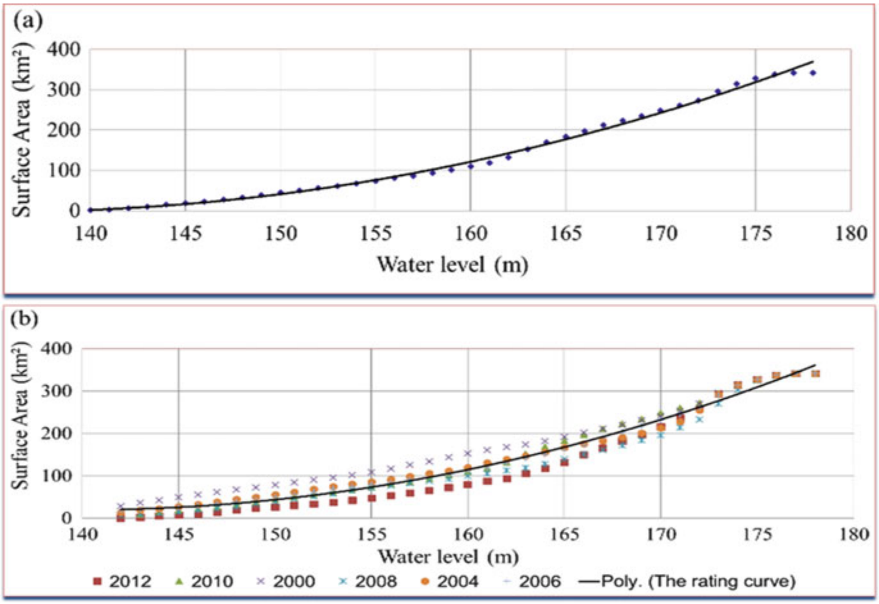

Fig. 15 Sample results of the rating curves (area/level): (**a**) 2010 rating curve and (**b**) collective rating curve for the years (2000–2012)

Table 5 Developed equations for the rating curves of the area/level for the years from 2000 to 2012

Period of the estimated rating curve	Number of points	R^2	RMSE (km^2)	RMSE (%)	Rating curve equation (y = surface area and x = water level)
2000	45	0.99	2.76	2.1	$y = 0.1249\ x^2 - 31.068\ x + 1923$
2004	40	0.99	3.70	2.8	$y = 0.1972\ x^2 - 53.803\ x + 3682.3$
2006	40	0.99	3.06	2.3	$y = 0.2203\ x^2 - 60.939\ x + 4229$
2008	38	0.99	3.32	2.7	$y = 0.2642\ x^2 - 75.287\ x + 5379.2$
2010	39	0.99	3.03	2.2	$y = 0.2054\ x^2 - 55.65\ x + 3766.8$
2012	37	0.99	3.07	2.5	$y = 0.33\ x^2 - 95.598\ x + 6932.7$
2010 and 2012	74	0.98	4.52	3.4	$y = 0.2683\ x^2 - 75.816\ x + 5365.4$
2000–2012	222	0.97	5.38	3.8	$y = 0.2348\ x^2 - 65.673\ x + 4612.5$

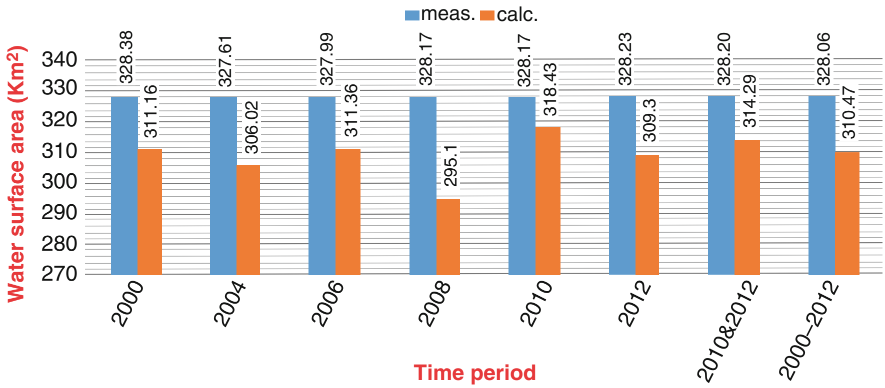

Fig. 16 Water surface area computed from the individual and collective rating curves at water level (175 m amsl)

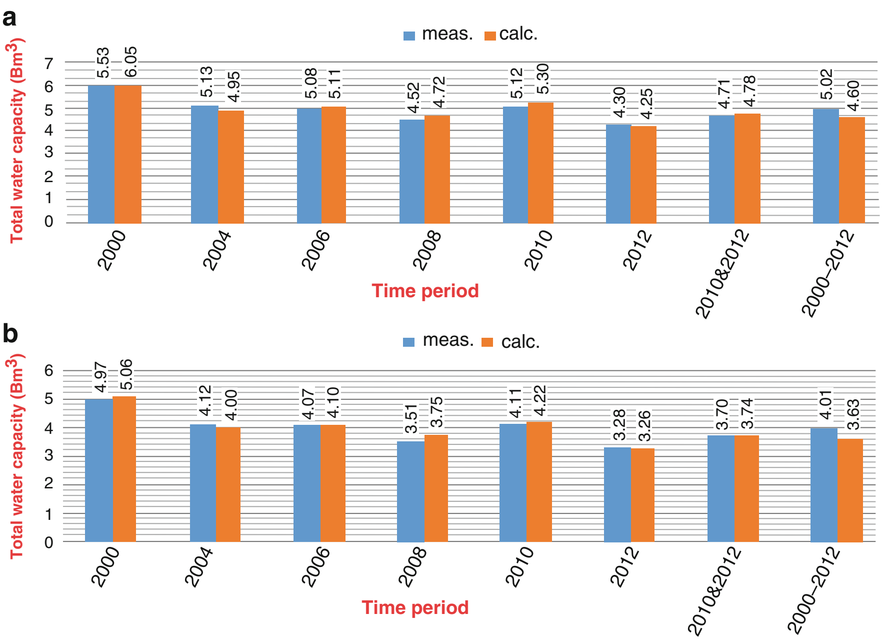

Fig. 17 Total water capacity computed from the individual and collective rating curves: (**a**) at water level (178 m amsl), (**b**) at water level (175 m amsl)

5.6 Effect of Sediment and Erosion Amounts on Water Capacity of the Study Area

Table 6 illustrates the effect of sediment and erosion change amounts on the measured water capacity from the years 2000 to 2012. It is obvious from this table that there is a decrease in the water capacity from the year 2000 to 2008 and from year 2010 to 2012 due to sediment accumulation (the amount of sediment is higher than the amount of erosion). Otherwise, there was an increase in the water capacity by 0.60 Bm^3 from year 2008 to 2010, because of the higher amount of erosion than the amount of sedimentation.

The previous results showed that by increasing the sediment amount more than the erosion amount, the water capacity decreases and vice versa.

5.7 Application and Comparisons

Table 7 illustrates that the sum of water volume of the AHDL active sedimentation portion that was estimated by AHDA and NRI (the traditional methods) was about

Table 6 Effect of sediment and erosion amounts on the water capacity

Year	Time period	Water capacity (Bm^3)	Difference between sediment and erosion = Total change amount (Bm^3)	Case	Type of total change
2000		4.97			
	2000–2004		0.85	Decrease in water capacity	Sedimentation
2004		4.12			
	2004–2006		0.05	Decrease in water capacity	Sedimentation
2006		4.07			
	2006–2008		0.56	Decrease in water capacity	Sedimentation
2008		3.51			
	2008–2010		−0.60	Increase in water capacity	Erosion
2010		4.11			
	2010–2012		0.83	Decrease in water capacity	Sedimentation
2012		3.28			

Table 7 Calculated water volumes of the study area by AHDA at water level (175 m amsl) at year 2012

Sec. code	Area (m^2)	Served length (km)	Volume (Bm^3)
22	190515.91	7.95	1.514
24	95818.63	7.25	0.695
25	98114.46	8.00	0.785
26	19233.31	6.00	0.115
27	8947.32	8.50	0.076
28	11884.96	4.00	0.047
			$\sum = 3.232$

Table 8 Comparison of results between the present and traditional methods of estimating sediment amount area from year 2000 to 2012

Time period	Amount of sediment by GIS/RS method (Bm^3)	Amount of sediment by AHDA method (Bm^3)
2000–2012	1.69	1.62

3.232 billion m^3 [24]. These values are nearly equal to the computed volume in this study using the RS/GIS approach at the same water level (175 m amsl) which has a value 3.26 billion m^3 as shown previously in Fig. 17b. This means that the present method overestimates the water capacity by less than 1%. Consequently, the developed equations can be used to estimate the water volume (capacity) of this part of the lake as an alternative to extensive costly measurements. However, field measurements by AHDA and NRI are necessary from time to time in order to update such equations and for monitoring purposes as well.

Table 8 illustrates that the total amount of sediment from year 2000 to 2012 was about 1.69 billion m^3 (sum of total change amount – between 2000 and 2012 – from Table 4), and the estimated sediment amount by the AHDA (the traditional method) was equal to 1.62 billion m^3 in the same period [24]. This means that the present approach overestimated the sedimentation capacity by about 4.3% compared to the method used by AHDA. This percent indicates that the AHDA and NRI sediment data are trustful and reliable.

6 Conclusions and Recommendations

This study presents and discusses the results of change detection in bed surface (sedimentation/erosion) of the active portion of Aswan High Dam Lake based on using RS/GIS techniques. The results indicate that sedimentation is dominant in years with high flood while erosion occurs when the incoming flow to the lake is low. The computed water capacities show an increase during the periods where erosion amounts exceed sediment amounts and vice versa. Moreover, results indicate that the present approach overestimates the sedimentation capacity by about 4.3% from year 2000 to 2012 compared to the results of the method used by AHDA. The measured velocity patterns are mapped, analyzed, and its 2-D profiles are correlated to changes of the study area bed profiles. According to this correlation, it can be concluded that the increment in the inflow velocity rate is associated with the erosion phenomenon. On the other hand, the decrement in the inflow velocity rate is accompanied with the sedimentation phenomenon. In addition, this study developed several relationships between water volume or capacity/ surface area/water level for the active sedimentation zone of Nubia Lake for the years from 2000 to 2012 individually and collectively. The accuracy of the developed relationships was assessed by comparing the results with the field measurements and the existing rating curves for the Lake. The RMSE was found to range between 5–10% and 2–4% for the relationships (volume/water level) and (surface area/water level), respectively. Also, the correlation coefficients ranged from 0.94 to 0.99 (volume/water level) and from 0.97 to 0.99 (area/water level). The authors highly recommend the use of the same tested method in this paper in studying the change detection of the entire AHDL. Also, it is recommended to jointly use the remote sensing and in situ data to provide an accurate estimate of water capacity (volume) variations and sediment amounts of the whole AHDL.

References

1. Ackermann WC, White GF, Worthington EB, Ivens JL (2013) Man-made lakes: their problems and environmental effects. Online ISBN: 9781118664117, Geophysical Monograph Series, the American Geophysical Union
2. Masundire HM (1994) Mean individual dry weight and length-weight regressions of some zooplankton of lake Kariba. J Hydrobiol 272:231–238
3. Babicheva VA, Rzetala MA (2014) The Angara reservoir cascade as a subject of the transport and tourism concern. Geogr Tour 2(1):29–33, Semi-Annual Journal
4. Kuznetsova AI, Zarubina OV, Leonova GA (2002) Comparison of Zn, Cu, Pb, Ni, Cr, Sn, Mo concentrations in tissues of (roach and perch) from lake BAIKAL and BRATSK reservoir, Russia. Environ Geochem Health 24:205–213, published © 2002 Kluwer Academic Publishers, Printed in the Netherlands
5. Shesterkin VP (2010) Centennial variation in the chemical composition of river water in the Khabarovsk water node. ISSN 1819-7140. Russ J Pac Geol 4(2):187–193. © Pleiades Publishing, Ltd
6. Feeley K (2003) Analysis of Avian communities in lake Guri, Venezuela. J Community Ecol (Oecologia) 137:104–113, published online© Springer-Verlag 2003
7. Schultz GA (1997) Use of remote sensing data in a GIS environment for water resources management. Remote Sensing and Geographic Information Systems for Design and Operation of Water Resources Systems (Proceedings of Rabat Symposium S3, April 1997). IAHS Publ. no. 242
8. Elsahabi M, Negm A, El-Tahan MA (2015) Performances evaluation of surface water areas extraction techniques using Landsat ETM+ data: case study Aswan High Dam Lake (AHDL). In: 9th international conference interdisciplinary in engineering, INTER-ENG, 8–9 October 2015, Tirgu-Mures, Romania

9. Elsahabi M, Negm A, Ali K (2016) Development of rating curves for Nubia Lake, Sudan, using RS/GIS. In: International Conference on Water, Environment, Energy and Society (ICWEES 2016), 15–18 March 2016, Bhopal, India
10. Curzio SL, Russ F, Caporaso M (2013) Application of remote sensing and GIS analysis to detect morphological changes in an artificial lake. Int J Remote Sens Geosci (IJRSG) 2(4), ISSN No: 2319-3484
11. El-Sammany MS, El-Moustafa AM (2011) Adaptation of surface water modeling system for sediment transport investigations in Lake Nasser. J Nile Basin Water Sci Eng 4(1):71–85
12. Negm MA, Abdulaziz T, Nassar M, Fathy I (2010) Predication of life time span of high Aswan dam reservoir using CCHE2D simulation model. In: 14th International Water Technology Conference, IWTC 14, Cairo, Egypt, pp 611–626
13. Sallam G, Ihab M, Emary W (2015) Study of Alaqi secondary channel in Nasser Lake. In: Eighteenth International Water Technology Conference, IWTC18, Sharm ElSheikh, Egypt, pp 298–309
14. Moustafa A (2013) Predicting the deposition in the Aswan high dam reservoir using a 2-D model. Ain Shams Eng J 4:143–153
15. Muala E, Mohamed Y, Duan Z, Zaag P (2014) Estimation of reservoir discharges from Lake Nasser and Roseires reservoir in the Nile Basin using satellite altimetry and imagery data. Remote Sens 6:7522–7545
16. Baup F, Frappart F, Maubant J (2014) Combining high-resolution satellite images and altimetry to estimate the volume of small lakes. Hydrol Earth Syst Sci 18:2007–2020
17. Medina C, Gomez J, Alonso J, Villares P (2010) Water volume variations in Lake Izabal (Guatemala) from in situ measurements and ENVISAT Radar Altimeter (RA-2) and Advanced Synthetic Aperture Radar (ASAR) data products. J Hydrol 382:34–48
18. Duan Z, Bastiaanssen W (2013) Estimating water volume variations in lakes and reservoirs from four operational satellite altimetry databases and satellite imagery data. Remote Sens Environ 134:403–416
19. Zhang J, Xu K, Yang Y, Qi L, Hayashi S, Watanabe M (2006) Measuring water storage fluctuations in Lake Dongting, China, by Topex/Poseidon Satellite Altimetry. Environ Monit Assess 115:23–37
20. Lee K (2013) Estimation of reservoir storage capacity using terrestrial Lidar and multibeam sonar, Randy Poynter Lake, Rockdale County, Georgia. In: Proceedings of the 2013 Georgia Water Resources Conference, held April 10–11, 2013, at the University of Georgia
21. Abileah R, Vignudelli S, Scozzari A (2011) A completely remote sensing approach to monitoring reservoirs water volume. In: Fifteenth International Water Technology Conference, IWTC 15, Alexandria, Egypt, pp 1–17
22. El Gammal EA, Salem SM, El Gammal AA (2010) Change detection studies on the world's biggest artificial lake (Lake Nasser, Egypt). Egypt J Remote Sens Space Sci 13:89–99
23. Ali MM (2006) Shoreline vegetation of Lake Nubia, Sudan. Hydrobiologia 570:101–105, Springer 2006
24. NRI (2012) Nile Research Institute. Annual reports for studying sediment transport and water quality in Aswan High Dam reservoir (1973–2012). National Water Research Center, Cairo, Egypt
25. MALR (2012) The Ministry of Agriculture and Land Reclamation, Egypt, the General Authority for AHDL Development, AHDL levels (1978 to 2012)
26. MWRI (2012) The Ministry of Water Resources and Irrigation, Egypt, Nile Water Sector. Annual report (2011–2012)
27. GLCF (2014) The Global Land Cover Facility, provides earth science data and products. Available from: http://www.glcfapp.glcf.umd.edu/data/landsat/. Last accessed: May 09, 2014
28. Ebaid H, Ismail S (2010) Lake Nasser evaporation Reduction Study. J Adv Res 1:315–322
29. Ling F, Cai X, Li W, Xiao F, Li X, Du Y (2012) Monitoring river discharge with remotely sensed imagery using river island area as an indicator. J Appl Remote Sens 6:063564 (1–14)

30. Xu H (2006) Modification of normalised difference water index (NDWI) to enhance open water features in remotely sensed imagery. Int J Remote Sens 27(14):3025–3033
31. Du Z, Linghu B, Ling F, Li W, Tian W, Wang H, Gui Y, Sun B, Zhang X (2012) Estimating surface water area changes using time-series Landsat data in the Qingjiang River Basin, China. J Appl Remote Sens 6:063609 (1–16)
32. Rokni K, Ahmad A, Selamat A, Hazini S (2014) Water feature extraction and change detection using multitemporal Landsat imagery. J Remote Sens 6:4173–4189
33. Ma M, Wang X, Veroustraete F, Dong L (2007) Change in area of Ebinur Lake during the 1998–2005 period. Int J Remote Sens 28:5523–5533
34. Elsahabi MA, Negm AM, Ali KA (2016) Performances evaluation of surface water areas extraction techniques using LANDSAT ETM+ data: case study of Lake Nubia, Sudan. In: International Conference of Engineering Sciences and Applications, ICESA 2016, Aswan, Egypt, pp 169–174
35. ESRI (2008) Environmental Systems Research Institute, Help topics of ArcGIS version 9.3 Desktop. Developer center of geographic information systems (GIS) software, Redlands, California
36. Elsahabi MA, Negm AM (2015) Change detection in erosion and sedimentation of the active sedimentation portion of Aswan High Dam Lake, Egypt, using RS/GIS techniques. In: The Association of Egyptian American Scholars (AEAS) 42nd Annual conference, 27–29 December 2015, Ain Shams University, Egypt
37. Elsahabi MA, Negm AM, Ali KA (2016) Correlating the velocity profiles to the sediment profiles of the active sedimentation zone of Aswan High Dam Lake. In: Proceedings of the nineteenth international water technology conference (IWTC19), Sharm ElSheikh, 21–23 April
38. Microsoft Corporation (2003) Microsoft office excel, product ID 73931-640-0000106-57348, USA

Water Quality Assessment of Aswan High Dam Reservoir

M. Elshemy and G. Meon

Abstract Egypt is highly dependent on the River Nile as the main source of freshwater. The Aswan High Dam (AHD) was constructed to control the River Nile. AHD reservoir was formed due to the construction of the dam; it is considered as one of the largest man-made lakes in the world. There is currently rising awareness regarding the water quality status of River Nile and in particular the AHD reservoir, the sole reservoir in Egypt. In this work, a comparative study to assess the water quality and trophic state of the southern part of AHD reservoir, Lake Nubia, has been done during low flood periods of 3 successive years (2006–2008). Two water quality indices (NSF WQI and CCME WQI) and two trophic status indices (Carlson TSI and LAWA TI) were used. The results show that the water quality status of Lake Nubia ranges from excellent (according to the Egyptian water quality standards for surface fresh waterways) to good, while the trophic status of the reservoir is eutrophic. A spatial change in results can be noticed due to the morphological and hydrological characteristics of the reservoir. It is recommended that the reservoirs' different zones should be assigned to different water uses based on comprehensive water quality studies.

Keywords AHD reservoir, Lake Nubia, River Nile, TSI, WQI

M. Elshemy (✉)
Faculty of Engineering, Tanta University, Tanta, Egypt
e-mail: m.elshemy@f-eng.tanta.edu.eg

G. Meon
Leichtweiss-Institute for Hydraulics and Water Resources (LWI), University of Braunschweig, Braunschweig, Germany

A.M. Negm (ed.), *The Nile River*,
Hdb Env Chem (2017) 56: 105–144, DOI 10.1007/698_2016_96,

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Abbreviation

AHD	Aswan High Dam
APHA	American Public Health Association
BCM	Billion cubic meter
CCME	Canadian Council of Ministers of the Environment
Chl-a	Chlorophyll a (mg/L)
DO	Dissolved oxygen (mg/L)
DO_{sat}	Dissolved oxygen saturation concentration (mg/L)
LAWA	Länderarbeitsgemeinschaft Wasser (German Regional Working Group on Water)
MWRI	Egyptian Ministry of Water Resources and Irrigation
NH_4	Ammonium (mg/L)
NO_2	Nitrite (mg/L)
NO_3	Nitrate (mg/L)
NSF	National Sanitation Foundation
OECD	Organization for Economic Cooperation and Development
pH	Potential of hydrogen (unit)
PO_4	Orthophosphate (mg/L)
St. n	Station number n
T	Temperature (°C)
TDS	Total dissolved solids (mg/L)
TI	Trophic level
TN	Total nitrogen (mg/L)
TP	Total phosphorus (mg/L)
TSI	Trophic status index
TSS	Total suspended solids (mg/L)
WQI	Water quality index

1 Introduction

The water quality state of a water body depends on a large number of physical, chemical, and biological indicators. Using an evaluation approach, such as the water quality index, can indicate the overall water quality condition.

Basically, there are four main approaches which are widely used to assess the water quality of a water body:

1. Water quality index approach
2. Trophic status index approach
3. Statistical analysis approaches of the water quality data such as correlation analysis [1–6] and fuzzy clustering analysis [7–11]
4. Biological analysis approaches such as genetic algorithms method and other different biological indices [12–33]

First, comprehensive studies are required to develop the statistical and biological approaches. This task was not within the frame of this research work but is recommended in future work. In this research work, water quality and trophic status indices will be used to assess the water quality state of Aswan High Dam (AHD) reservoir.

2 State of the Art

2.1 Water Quality Indices

A water quality index (WQI) can be simply defined as a mathematical approach which aggregates data on two or more water quality variables to produce a single number [34]. It consists of water quality variables such as dissolved oxygen, total phosphorus, and fecal coliform, each of which has specific impacts to beneficial uses. The water quality index concept was first introduced more than 160 years ago, in 1848, in Germany where presence or absence of certain organisms in water was used as an indicator of the fitness of a water source [35].

There are several water quality indices that have been developed to assess water bodies. In 1965, the first-ever modern WQI was developed and published by Horton [36]. Horton's index uses ten variables, including commonly monitored ones such as dissolved oxygen, fecal coliform, and temperature. It is computed as the weighted sum of subindices, which are calculated using a table of specific subindex values corresponding to range of each variable. Horton's index ranges from 0, representing poor water quality, to 100, representing perfect water quality [34].

Development of water quality indices has been discussed in numerous publications [37–42]. Abbasi and Abbasi [37] presented a comprehensive review for WQIs approaches, formulation, and types. Walsh and Wheeler [42] discussed the development of WQIs according to the applied aggregation methods. According to

Table 1 A statistical description of WQIs publications during the period (1974–2011) [40]

Type of water use	Public use	Agriculture	Water reuse	WTP	Fish farms
	76.3 %	19.8 %	13.5 %	8.01 %	5.9 %
WQI	Total number	New WQI	Most frequently used WQI		
	97 WQIs	20 %	NSF WQI		
Study region	India	China	Brazil	USA	Other
	38 %	9.6 %	5.5 %	4.5 %	42.4 %
Water body	Rivers and streams	Other			
	57 %	43 % (lakes, artesian wells, reservoirs, groundwater, flood plains then aquifers)			

Poonam et al. [39], WQIs can be classified into four main groups: public indices, specific consumption indices, planning indices, and statistical indices. The authors reviewed 13 frequently used WQIs. Ribeiro Alves et al. [40] discussed, in their review publication, the state of scientific literature on WQIs. The authors reviewed 554 articles which were published during the period (1974–2011). The main findings of this study can be seen in Table 1. In 2016, Sutadian et al. discussed the development and the application of WQIs for rivers during the period 1987–2014. Out of the 30 reviewed WQIs, the authors addressed seven WQIs as the most important indices, based on their wider use. These indices are ordered as the following: CCME WQI, NSF WQI, Oregon Index, Bascarón index, House's Index, Scottish Research Development Department index, and Fuzzy-based indices. The authors presented a list of the reviewed WQIs and their different applications [41].

For Egyptian water resources, different WQIs have been used. Table 2 shows a list of recent WQI applications for Egyptian water resources.

Since 1965, many different water quality indices have been addressed in the literature [62–80].

Two of the best known water quality indices, which have been frequently used, are the National Sanitation Foundation Water Quality Index (NSF WQI) and the Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI). The two indices were chosen for this research work.

The NSF WQI has been widely applied to many water bodies [81–89]. NSF WQI, or variants of it, is used by a number of state agencies in the United States in their annual reports on the water quality of rivers and streams under their jurisdiction [73]. NSF WQI was used to represent the water quality profile of Yamuna River, India [87]. Bonanno and Lo Giudice [17] used the NSF WQI and a floristic quality index. The former enabled them to describe the water quality according to a spatial–temporal gradient, whereas the latter focused on the ecological quality of riparian vegetation.

Table 2 List of recent selected WQI studies for Egyptian water resources (2011–2016)

Year	WQI	Application	No. of WQ parameters	Reference
2011	Bascaron WQI	The beaches at Matrouh City	7	[43]
2012	EWQI (CCME)	Omar Bek drain and Damietta branch	17	[44]
2012	NSF WQI	Groundwater of eight rural governorates (Qena, Sohag, Kalubiya, Menofiya, Sharqiya, Gharbiya, Kafr El-Sheikh, and Daqahliya)	9	[45]
2012	PCA WQI	Kilo 21, Oumum, and Nubaria drains, Alexandria	33	[46]
2012	Bascaron WQI	Groundwater of Darb El-Arbaein area, South-western Desert	20	[47]
2013	CCME WQI	El-Nubaria and El Mahmoudia, El Hager, El Nassr, El Khandak, and Abo Diab Canals	17	[48]
2014	Bascaron WQI	Ismailia Canal	34	[49]
2014	Bascaron WQI	Groundwater of Darb El-Arbaein	8	[50]
2014	CCME WQI	Mahmoudia Canal	20	[51]
2014	EWQI (CCME)	El-Kurimat power steam plant on the River Nile	17	[52]
2014	PCA WQI	EL-Dekhaila Harbor, Alexandria	11	[53]
2014	PCA WQI	El-Mex bay, El-Umum Drain, El-Qalaa Drain, El-Noubaria Drain, and Marriott Lake, Alexandria	14	[54]
2014	Bascaron WQI	El-Omumm Drain and Nubaria Canal, Alexandria	19	[55]
2015	Bascaron WQI	Groundwater of Western Nile Delta	21	[56]
2015	Bascaron WQI	Rosetta Branch	6	[57]
2015	CCME WQI	20 drains discharging to Northern Egypt Lakes and the Mediterranean Sea	11	[58]
2015	CCME WQI	River Nile in Cairo governorate	9	[59]
2015	DWRI	Gharbia drain in the Nile Delta	5	[60]
2016	Bascaron WQI	Groundwater of Assiut governorate, Egypt	15	[61]

The CCME WQI has been applied to several data sets nationally (in Canada) and internationally [90–99]. In 2008, the CCME WQI was modified according to the Egyptian guidelines (for drinking surface water) and was applied at four stations of the River Nile, Egypt [100]. De Rosemond et al. [101] evaluated the ability of the CCME WQI to differentiate water quality from metal mines across Canada at exposure sites from reference sites using two different types of numeric water quality objectives. CCME WQI and NSF WQI were applied for the Karun River system which is considered as the most important river in Iran [102]. Boyacioglu [103] has modified the CCME WQI to meet requirements of classification of surface waters according to quality based on European legislation. Then, the developed WQI has been applied to assess the overall water quality in the Kucuk Menderes Basin, Turkey. The CCME WQI was used to assess the water quality of the River Chenab, Pakistan, during the low-flow months of 2006–2007 and 2007–2008 [104].

2.2 *Trophic Status Indices*

The trophic state does not directly imply the water quality but assigns the productivity of the water body due to the occurring biological and chemical activities and is dependent on nutrient concentrations and other characteristics. Lakes and reservoirs, according to their biological productivity and nutrient conditions, are commonly grouped into three different trophic states: oligotrophic, mesotrophic, and eutrophic. The trophic state falls under two terms “oligotrophic” (Greek for ‘little food’) or “eutrophic” (Greek for ‘well fed’) and was originally used to describe the soil fertility in northern Germany; subsequently, these terms were applied to lakes [105].

Numerous attempts have been made to define the trophic states in terms of both nutrient and productivity water quality parameters. Carlson [106] developed a numerical trophic state scale from 0 to 100 for lakes. The index number can be calculated from any of several parameters including Secchi depth transparency (SD), chlorophyll (Chl-a), and total phosphorus (TP). The Carlson TSI has been widely used to evaluate many lakes and reservoirs [107–114]. Galloway and Green [115] used TSI (TP) and TSI (CHL) to assess the trophic status of lakes Maumelle and Winona, Arkansas, USA. In 2010, Santhanam and Amal Raj [116] have used the Carlson TSI to determine the trophic status of Pulicat lagoon, India, for the years 2005 and 2006. All the values obtained for the TSI (SD) were higher when compared to the TSI (Chl-a), which may indicate that something other than algae, perhaps color or non-algal seston or the dominance by pico-plankton, is contributing to the light attenuation. The investigation relays the need to develop more modern and more accurate indices to represent water quality in a lagoon. The trophic status of Manzala Lake, Egypt, was evaluated using Carlson TSI [117–119]. N/P ratio also was calculated to determine the limiting nutrient for the lake. Ahmed et al. [117] concluded that the lake trophic state is eutrophic and hypereutrophic in those parts of the lake closest to the drain outlets, and most of the lake area (96%) is limited by the nitrogen. Chang and Liu [109] examined the influence of water turbidity on the reliability of Carlson TSI and used the Back-Propagation Neural Network model to create a new trophic state index. In 2016, Carlson TSI was used to investigate the phosphorus dynamics of the aquatic system (East Kolkata Wetlands, India) during the wastewater purification process [120]. The authors indicated that the wetland maintained a mesotrophic status after the onset of aerobic condition.

The Florida Department of Environmental Protection has developed a new trophic status index (using data for 313 Florida lakes), Florida Trophic State Index, which is based on the Carlson TSI but also includes total nitrogen as a third indicator [121, 122]. For Florida water quality assessment reports, the Secchi depth has been excluded as an indicator because of the associated problems which have been caused in dark-water lakes and estuaries, for which dark waters rather than algae diminish transparency. This index has been recently used [120, 123, 124].

In 1982, a detailed classification system based on the German technical standards was developed and has been used successfully for lakes and reservoirs located primarily in temperate zones as well as in some non-temperate situations [105, 125]. This detailed classification system evaluates the water quality of a water body by using three main criterion classes: hydrographic and territorial criterion, trophic criterion, and salt content, special, and hygienically relevant criterion [105].

The Organization for Economic Cooperation and Development [126] provides specific criteria for temperate lakes in terms of the mean annual values of total phosphorus, chlorophyll a, and Secchi depth (Table 3). These criteria have

Table 3 Trophic classification of temperate freshwater lakes, based on a fixed boundary system [126, 127]

	Trophic category				
	Ultra-oligotrophic	Oligotrophic	Mesotrophic	Eutrophic	Hypertrophic
Nutrient concentration (μg/L)					
Total phosphorus	<4	4–10	10–35	35–100	>100
Orthophosphate	<2		2–5	5–100	>100
DIN	<10		10–30	30–100	>100
Chlorophyll a concentration (μg/L)					
Mean concentration in surface water	<1	1–2.5	2.5–8	8–25	>25
Max. concentration in surface water	<2.5	2.5–8	8-25	25–75	>75
Secchi depth (m)					
Mean annual value	>12	12–6	6–3	3–1.5	<1.5
Minimum annual value	>6	>3	3–1.5	1.5–0.7	<0.7

limitations in practical use; some water bodies can be classified in one or another trophic category depending on which parameter is used. Lake Baikal, Russia, for example, is ultra-oligotrophic in terms of physicochemical characteristics but is close to mesotrophic on the basis of primary production [127]. To avoid this, a more flexible open boundary system has been developed by OECD by using a statistical fit to more open ranges of the parameters. OECD criteria have been used for estimating the trophic status of several lakes and reservoirs [112, 128–132].

For coastal marine waters, Vollenweider et al. [133] proposed a new trophic index (TRIX), which is based on Chl-a, oxygen saturation, mineral, total nitrogen, and phosphorus. This index has been frequently used to evaluate the trophic status of coastal marine waters, estuaries, and lagoons [134–140].

In 1999, a new trophic level index (TLI) was developed to estimate the trophic level of New Zealand lakes and reservoirs [141]. TLI is based on Chl-a, TP, SD, and TN. This index is used in recent studies [142, 143].

The OECD concept has been modified by the German Regional Working Group on Water, Länderarbeitsgemeinschaft Wasser [144]. The LAWA Total Index (TI) is more flexible and can be calculated by different methods. LAWA TI has been widely used in Germany; it has been used to assess 23 reservoirs in Saxony [145]. The Rappbode Dam reservoir in Saxony-Anhalt has been evaluated using LAWA TI. The reservoir trophic status was mesotrophic; LAWA TI was less than 2.0 [146]. The Ruhrverband [147] used the LAWA TI to assess eight reservoirs in different sites in Germany. The Hessian Agency for Environment and Geology [148] has applied LAWA TI to 90 water bodies (lakes and reservoirs) in Hessen for the water quality measurement in 2007. Scharf [149] used the LAWA TI to evaluate the Wupper Reservoir which is situated in central western Germany.

For reservoirs, based on their morphological characteristics, there is often a spatial gradient in sediment and nutrient concentration patterns along the body of a reservoir, especially in long, narrow, dendritic reservoirs. This gradient is accompanied by a spatial gradient in biological productivity and water quality in the reservoir [105]. The trophic status may range from nutrient rich (eutrophic) in the upper reaches of the water body to nutrient poor (oligotrophic) at locations closer to the dam wall [150]. Lind et al. [151] suggested that according to the gradient in trophic status in reservoirs, a corresponding zonation exists in the relative suitability of various portions of reservoirs for different uses (e.g., water supply, fishing, and recreational activities). Moreover, they stated that two different methods should be used for estimating the trophic status of reservoirs.

Some interesting trials to develop a new trophic index to evaluate tropical/subtropical reservoirs were done in Brazil [152–154]. The Trophic Status Index for tropical/subtropical reservoirs (TSI_{tsr}) is the most recently developed one in Brazil [152]. This index, which is considered as a calibrated version of Carlson TSI, is based only on Chl-a and TP. Secchi depth (SD) was excluded as this parameter is affected by turbidity due to suspended material which is common in reservoirs. The data of 18 tropical/subtropical reservoirs in Brazil were used for developing this index which has been used to evaluate different reservoirs in Brazil [78, 155, 156].

In the literature, many different trophic indices have been developed [8–10, 26, 157–171].

Two trophic status indices were chosen for this research work: Carlson TSI and LAWA TI.

3 Case Study: Aswan High Dam Reservoir

3.1 Study Area

Egypt is extremely dependent on the River Nile; the country hardly has any other freshwater resources [172]. Full control of the Nile water discharge was achieved in the 1970s after the construction of the Aswan High Dam (AHD). As a result, the AHD reservoir was formed. The reservoir extends about 500 km upstream from the Aswan High Dam between the latitudes 23° 58′ and 20° 27′ N and between longitudes 30° 35′ and 33° 15′ E (Fig. 1). The current length of the submerged area is about 500 km, of which 350 km are within the Egyptian territory and is known as Lake Nasser. The 150 km stretch which lies in the northern part of Sudan is known as Lake Nubia. Generally, the reservoir is also known as Lake Nasser reservoir. AHD reservoir has a long, narrow shape with dendritic side arms or bays (Khours) extending in both the Egyptian and Sudanese stretches of the Nubian Nile (Fig. 2).

Lake Nasser reservoir is situated in a desert area; the climate is extremely arid. The area is in the transition zone between the tropical climate with summer rain and the Mediterranean climate with winter rain [173]. This area receives virtually no

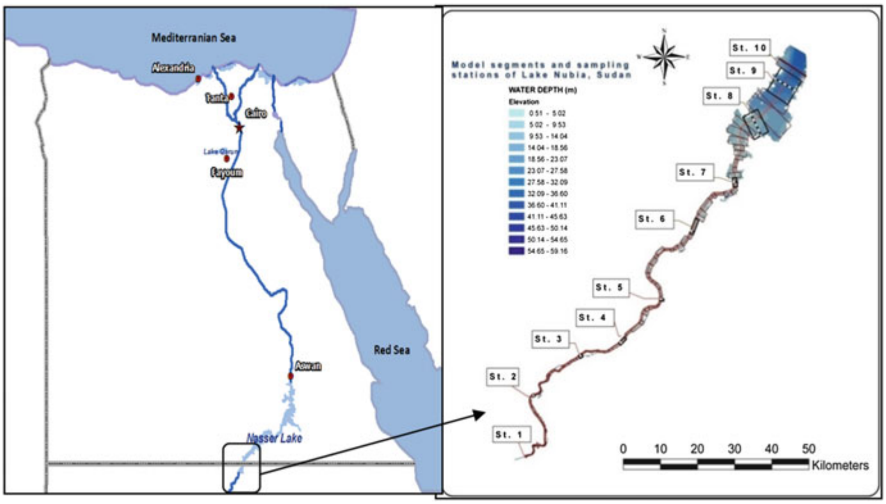

Fig. 1 Map of Lake Nubia and its selected sampling stations (control stations)

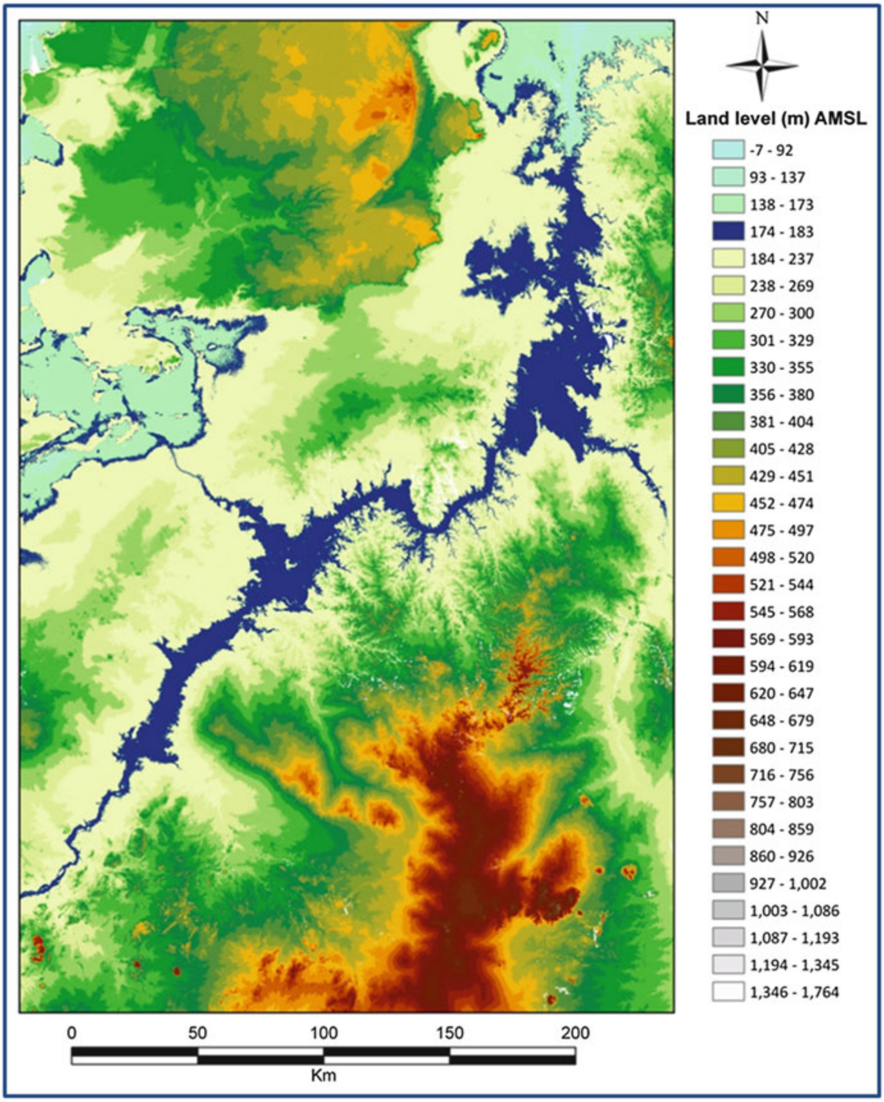

Fig. 2 AHD reservoir region topography

rainfall, except for occasional thunderstorms in winter, roughly once every 10 years [174, 175]. The relative humidity is highest (40–41 %) in December and January and lowest in the May and June (13–15 %). The wind speed does not vary greatly all over the year, as the mean ranges from about 15 to 19 km/h. Its direction is mostly NW-NE [175]. Evaporation is very high, approximately 3,000 mm/year [176].

The reservoir has a maximum water depth of 130 m (the mean depth is about 25 m), or 182 m above mean sea level (AMSL), and a total capacity of 162 BCM (about 15 % of that for Lake Nubia). At this level the reservoir has a length close to 500 km (about 150 km for Lake Nubia) and an average width of 12 km. The surface area of the reservoir at this maximum water level is 6,540 km^2. Lake Nubia has about 14.8 % of the total surface area. Figure 2 shows the topography of the reservoir region, while Fig. 3 shows the water level – reservoir volume – surface area curve. Further details about the reservoir morphology can be found in [174, 175, 177–179].

Lake Nubia can be divided into two sections: the riverine section and the semi-riverine section [175]. The riverine section, with all-year riverine characteristics, comprises the southern part of the lake, from the southern end to Daweishat (St. 5), as shown in Fig. 1. The semi-riverine section, with riverine characteristics during the flood season (from the second half of July to November) and lacustrine characteristics during the rest of the year, covers the northern part of the lake extending from Daweishat. The study area has a desert climate. This area receives virtually no rainfall, except for occasional thunderstorms which may sporadically penetrate the area in winter roughly once every 10 years [175].

The reservoir water velocity decreases as it approaches the High Dam. At the entrance of the reservoir, the flow velocity is about 0.5 m/s. This velocity is gradually reduced within a few kilometers to 0.1–0.2 m/s and in Lake Nasser to 0–0.03 m/s [176]. The Nile flood usually carries about 134 million tons of suspended matter (silt) per year, based on the average yearly inflow of 84 km^3 [180]. It is heavily loaded with inorganic clay, silt and sand, and organic debris (detritus) [177]. About 98 % of the annual sediment load occurred during the flood season [175]. Almost all the silt brought by the River Nile is deposited within Lake

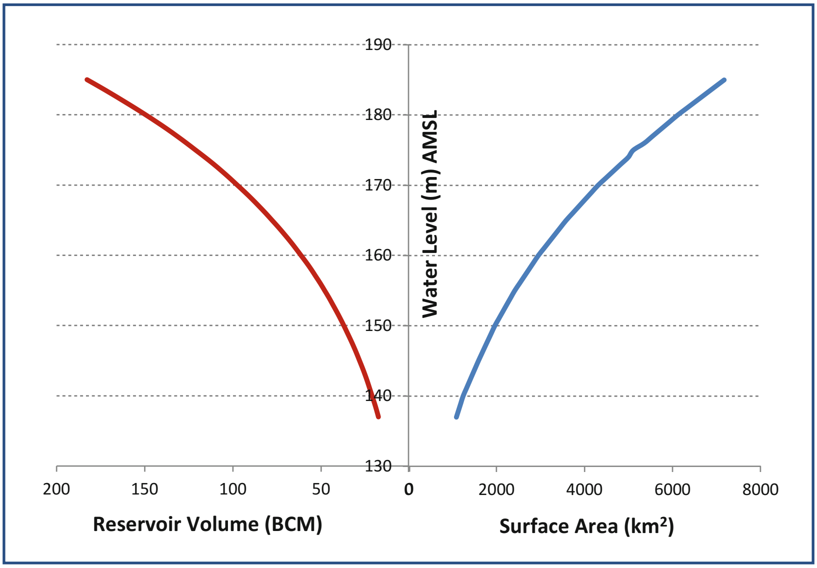

Fig. 3 AHD reservoir water level – volume – surface area curve

Nubia, most of it being deposited south of Haifa, where a new delta is in formation, and only the fine silt enters Lake Nasser [173]. Deposition in the reservoir is governed by a number of factors; the major factor is the sudden decrease of flow velocity as soon as it reaches the open area of Lake Nubia. The water losses of the reservoir are mainly due to evaporation and seepage. Annual evaporation losses are estimated at about 9.6 km^3, while annual seepage losses are estimated at 0.05 km^3 [180]. AHD reservoir has only one inflow source, the River Nile, at its upstream end. The inflow data were specified as daily average values from one gauging station at the upstream end of the reservoir. Figure 4 shows AHD reservoir inflows, monthly average, through the period from August 1998 to November 2007, as typical inflow for the reservoir. The reservoir inflow for successive 2 years is enlarged, as can be seen in Fig. 4. Typical flood period is from July to November, as can be seen in Fig. 4, while typical low flood period is from December to June.

The Egyptian Ministry of Water Resources and Irrigation, MWRI, has implemented an environmental monitoring program for AHD reservoir water quality [181]. MWRI realized the importance of protecting the reservoir from pollution, as it is almost the sole source of freshwater to the country. MWRI suggests that AHD reservoir and a strip of 20 km wide on both sides should be announced as a natural protectorate. Generally, from samples collected before and after the flood, the reservoir water has good physical and chemical characteristics for use [180]. The thermal pattern of the reservoir is warm monomictic; the reservoir stratifies in summer, and mixing occurs in winter [182]. Transparency is affected by the turbidity caused by silt and clay of riverine origin. It is particularly strong in the flood season. Water temperature ranges between 15.0°C in February and 32.4°C in August, pH is normally alkaline, and the reservoir trophic status is

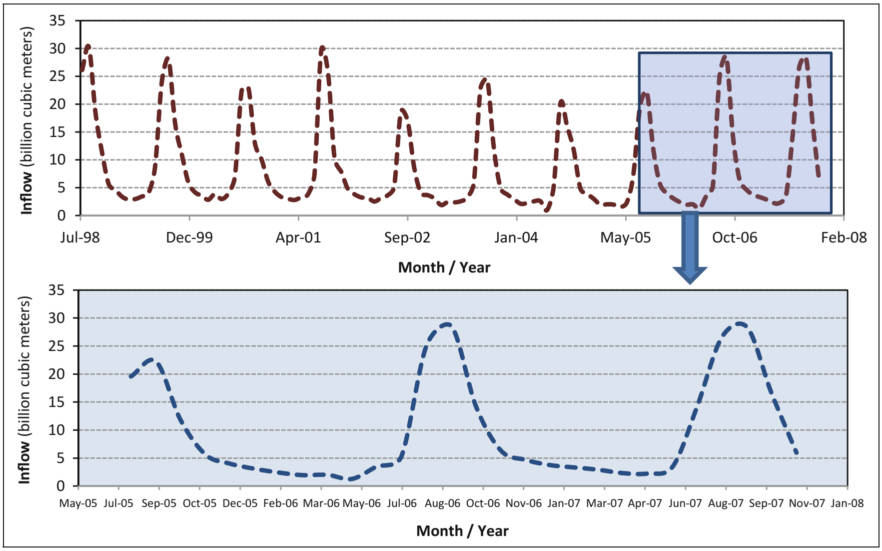

Fig. 4 AHD reservoir monthly inflows (1998–2007)

eutrophic [176]. Dissolved oxygen is usually high during November–April and low during May–October. In surface waters, concentrations often vary between 3 and 12 mg/L, but in deeper layers, they may be much less: 0–8 mg/L. Salinity is low at all times and generally <200 mg/L. Recorded concentrations for orthophosphate have ranged from 0.001 to 2.2 mg/L [182]. The phytoplankton community is composed of blue-green algae, diatoms, green algae, and dinoflagellates. Blue-greens dominate the community during spring and summer, while diatoms dominate the community only in winter [183]. Further details about the reservoir water quality can be found in [174, 184–186].

3.2 Data Collection

The southern part of Lake Nasser (AHD) reservoir which lies in Sudan, Lake Nubia, was chosen as the case study of this work due to the availability of different required data. Hydrodynamic and water quality data of Lake Nubia for January 2006, February 2007, and March 2008 were provided by Nile Research Institute (NRI) and National Water Research Center (NWRC), Egypt. The measured hydrodynamic and water quality data consist of water temperature, dissolved oxygen, chlorophyll a, orthophosphate, total phosphorus, nitrate–nitrite, ammonium, total dissolved solids, total suspended solids, turbidity, fecal coliform, and pH. In site parameters have been analyzed in a mobile Water Quality Laboratory, while other parameters have been analyzed in the NRI Water Quality Laboratory. The collected samples were analyzed using standard methods of American Public Health Association (APHA) [187].

In-reservoir temperature and constituent concentration profiles were measured at 18 sampling stations positioned along the longitudinal axis of Lake Nubia, as seen in Fig. 5. At each station, the water samples were collected from the surface and at 25, 50, 65, and 80 % of depth at three different vertical axes (east, middle, and west). Chlorophyll a samples were collected from different two zones, lighted and dark zones. Fecal coliform samples were collected from the surface and at 50 and 80 % of depth. Figure 6 shows surface measured concentrations of two selected parameters, DO and TSS, at different sampling stations along Lake Nubia, as examples.

3.3 Historical Review and Research Deficits

Studies regarding water quality evaluation of Aswan High Dam (AHD) reservoir in the literature are limited. Most of these studies were based on statistical approaches [188–191] or biological approaches [192–194].

In 1995, Awadallah and Soltan used a statistical approach to follow up the distribution of physical and chemical components between surface and bottom

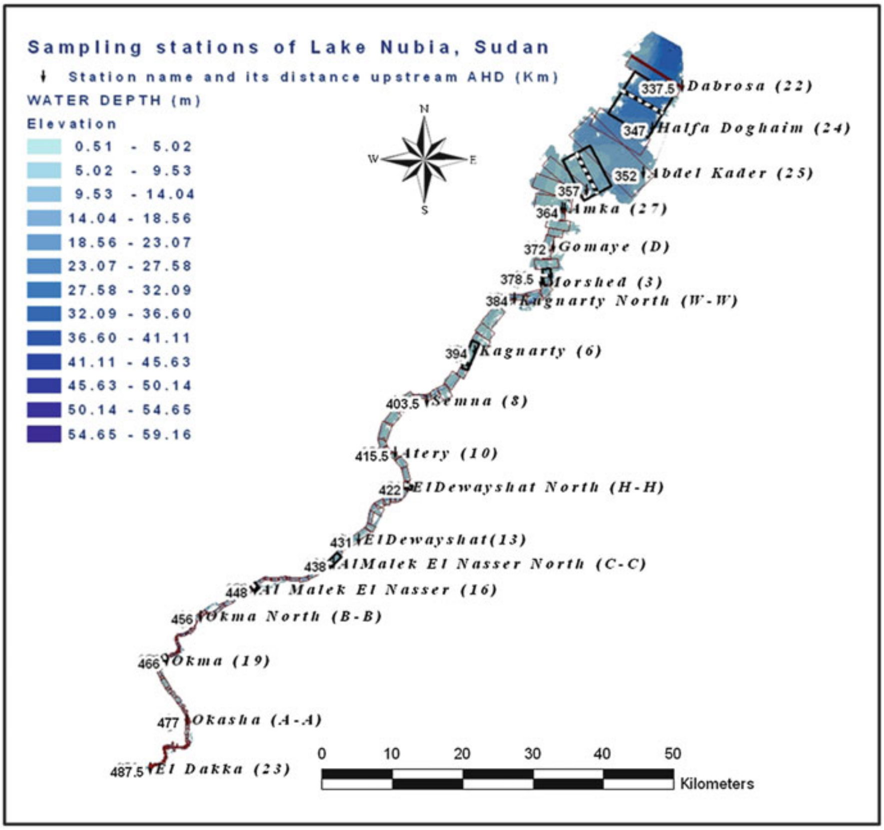

Fig. 5 Lake Nubia sampling stations

water of the AHD reservoir and their effects on the water quality and on the life of biota [195]. The samples were collected between Daal Cataract in Sudan and the AHD in the most southern part of Egypt, during the period from 23 November to 18 December 1992, at five different water depths. The statistical analysis of the database exhibited positive and significant correlation coefficient values. The results show that there was stratification in the water column of the reservoir.

The NSF WQI has been used by Abdel Rehim et al. [81] during the stratification period, extending from May to July, and turnover period, extending from September to December. The results revealed that the quality of water in Lake Nasser is improved during turnover and mixing periods. Average NSF WQI results were ranged between 62.00, medium, in July to 79.64, good, in November. The measured data were collected from one site in Lake Nasser, Abu Simbel (281 km upstream AHD), for 1 year (September 2000 to August 2001), and at different depths.

Abou El Kheir et al. [196] studied the seasonal variations of physical–chemical characteristics and phytoplankton growth at seven stations along Lake Nasser

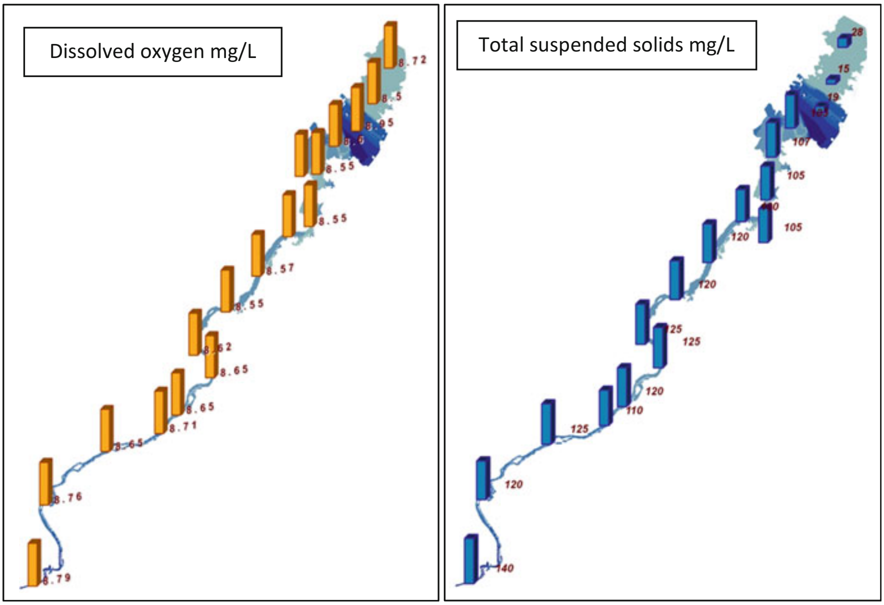

Fig. 6 Surface measured concentrations of some selected parameters at different sampling stations along Lake Nubia, January 2006

during the period 2001–2002. They stated that phosphorus is the limiting nutrient around the year. The Carlson TSI was used. The results show that Lake Nasser is a mesotrophic lake; its average TSI values range from 40 to 60. The TSI based on CHL was considerably lower than the TSI based on SD, especially in the south part of the lake. These results indicate that particles other than phytoplankton may be contributing to the light attenuation, where in this part of the lake, the water is turbid due to suspended sediment because of the flood or due to re-suspension from the bottom by turnover process.

A statistical mathematical model, based on regression relations of water quality parameters, was built up to estimate daily water quality parameters [197]. A fixed laboratory at the entrance of the reservoir was assumed using the available data (1977–2001). A physical, chemical, and biological analysis of the water quality was performed at 25 sections distributed along the lake using the World Health Organization (WHO) standards. According to WHO standards, the average water quality results before the flood are good, while during the flood are satisfactory except for the turbidity.

Gharib and Abdel-Halim [198] used statistical regression models to study the species composition, abundance, and phytoplankton biomass, supported by some physicochemical environmental parameters, in Lake Nasser during the highest flood season in autumn 1999. The results showed that the most relevant physicochemical factors affecting the growth of phytoplankton abundance were pH values, dissolved phosphate, and reactive silicate.

Heikal et al. [84] investigated the temporal and spatial variation of water quality status along the River Nile and the agricultural drains, which are the main sources of pollution along the Nile, during high- and low-flow periods from 2000 to 2005. Statistical analysis and NSF WQI were used. The results showed that the overall water quality status of the River Nile and the agricultural drains during the low-flow period is generally better than during the high-flow period. They concluded that the temporal and spatial variations in the water quality parameters along the River Nile are mainly affected by the quality of water discharges from agricultural drains as well as the magnitude of the River Nile flow.

Toufeek and Korium [6] studied the variations of physicochemical parameters in the main channel of Lake Nasser during the year 2005. Results indicated wide variations in the concentrations of different physicochemical parameters between surface and bottom layers during summer season especially in the northern part of the Lake. During winter, the variation in concentrations of these parameters between surface and bottom layers was modest. Correlation coefficient matrices between each two pairs of parameters were estimated to throw light on relationships between different physicochemical parameters. It was concluded that the various parameters under investigation in different seasons and regions in Lake Nasser lie within the permissible range, and the reservoir water quality status for drinking, irrigation, and fish culture purposes is good.

Heikal [199] investigated the quality of water in the main side branches (Khors) of Lake Nasser and its main channel during periods of low and high water levels for the years 2001 and 2005, respectively. He has used the NSF WQI and Carlson TSI to assess the water quality and trophic states, respectively, of Lake Nasser and main Khors. The results showed that the reservoir water level drop led to a decline in the water quality state of Lake Nasser and Khors from the order of good to medium. Also the trophic state index (TSI) values revealed that the productivity of the lake changed from mesotrophic during the high water level season to eutrophic during the low water level season.

NSF water quality index (WQI) and Carlson trophic status index (TSI) are the most frequently used indices for Egyptian water resources (see the previous section). In this research work, a comparative study has been done by applying other different two indices (additional to NSF WQI and Carlson TSI). These indices are CCME WQI and LAWA TI. The comparative study is essential to evaluate the water quality and trophic status for reservoirs in particular [151]. CCME WQI was developed according to the Egyptian water quality standards for surface fresh waterways. Carlson TSI was calculated for each of two water quality parameters, total phosphorus, and chlorophyll a, while the average Carlson TSI was calculated using both parameters, as recommended for reservoirs by Lind et al. [151].

3.4 Methodology

3.4.1 NSF WQI

The NSF WQI has been developed by the National Sanitation Foundation (NSF) in 1970 [62]. A survey of 142 water quality scientists was conducted to conclude which water quality tests should be included in an index, out of about 35 tests. Nine water quality variables are used for the index: dissolved oxygen (DO), fecal coliform, pH, biochemical oxygen demand (BOD), temperature change, total phosphate, nitrate, turbidity, and total solids. The index is computed as the weighted sum of subindices. Each parameter has a weight factor based on its importance in water quality (Table 4) and a rating curve gives a subindex quality value, which ranges from 0 to 100, corresponding to the field measurements. The NSF WQI can be calculated as follows:

$$\text{NSF WQI} = \frac{\sum_{i=1}^{n} W_i{*}Q_i}{\sum_{i=1}^{n} W_i} \tag{1}$$

where:

W_i	Weight factor of the *i*th parameter
Q_i	Quality of the *i*th parameter can be obtained from the appropriate subindex rating graph

The WQI ranges have been defined as [62]:

- 90–100: Excellent
- 70–90: Good
- 50–70: Medium
- 25–50: Bad
- 0–25: Very bad

Table 4 NSF WQI weight factors

Parameter	Weight factor
Dissolved oxygen (%sat)	0.17
Fecal coliform (#/100 mL)	0.16
pH (standard units)	0.11
Biochemical oxygen demand (mg/L)	0.11
Temperature change (°C)	0.10
Total phosphate (mg/L)	0.10
Nitrates (mg/L)	0.10
Turbidity (NTU)	0.08
Total suspended solids (mg/L)	0.07

According to the available water quality parameter measurements of Lake Nubia, eight parameters were used to apply NSF WQI to Lake Nubia. The used parameters are dissolved oxygen (% sat), fecal coliform (colonies/100 mL), pH (standard unit), temperature change (°C), total phosphate (mg/L), nitrate (mg/L), turbidity (NTU), and total solids (mg/L).

For temperature change, it is calculated as the difference between the water temperature value of the intended control station and its reference water temperature value. An expression for the dissolved oxygen saturation concentration (DO_{sat}) at sea level for freshwater as a function of water temperature which is given in APHA [187], Eq. (2), was used to calculate DO (% sat) at different control stations, Eq. (3). The used expression was as follows:

$$\ln DO_{sat} = -139.34411 + \frac{1.575701 \times 10^5}{T_w} - \frac{6.642308 \times 10^7}{T_w^2} + \frac{1.243800 \times 10^{10}}{T_w^3} - \frac{8.621949 \times 10^{11}}{T_w^4} \quad (2)$$

And then:

$$DO\ (\%\ sat) = \left({}^{DO_i}/{}_{DO_{sat}}\right)\% \quad (3)$$

where:

DO_{sat}	Freshwater DO saturation concentration in mg/L at sea level
T_w	Water temperature in (°K) ([°K] = [°C] + 273.150)
DO_i	Measured or simulated DO concentration at the control station St. *i*

3.4.2 CCME WQI

In 1997, the Canadian Council of Ministers of the Environment (CCME) developed a WQI to simplify the reporting of complex and technical water quality data. The WQI Technical Subcommittee adopted the conceptual model from the British Columbia index [63].

The application of the CCME WQI provides a measure of the deviation of water quality from water quality guidelines or objectives. Therefore, for each site and water use, different sets of parameters can be used depending upon the availability of data and regulatory standards.

The CCME WQI consists of three measures of variance from selected water quality objectives (scope, frequency, amplitude). These three measures of variance are combined to produce a value between 0 and 100 that represents the overall water quality. The CCME WQI values are then converted into rankings by using an index categorization schema that can be customized to reflect expert opinion by users. The detailed formulation of the WQI is described in the Canadian Water Quality Index 1.0 – Technical Report [63].

After the body of water, the period of time, the variables, and the objectives have been defined, each of the three factors that make up the index must be calculated as follows:

F_1 (scope) represents the percentage of variables whose objectives are not met in terms of "failed variables":

$$F_1 = \left(\frac{\text{Number of failed variables}}{\text{Total number of variables}}\right)100 \tag{4}$$

F_2 (frequency) represents the percentage of individual tests that do not meet objectives in terms of "failed tests":

$$F_2 = \left(\frac{\text{Number of failed tests}}{\text{Total number of tests}}\right)100 \tag{5}$$

F_3 (amplitude) represents the amount by which failed test values do not meet their objectives. F_3 is calculated in three steps:

1. The number of times, by which an individual concentration is greater than (or less than, when the objective is a minimum) the objective, is termed an "excursion" and is expressed as follows.
   When the test value must not exceed the objective:

$$\text{Excursion}_i = \left(\frac{\text{Failed test value}_i}{\text{Objective}_j}\right) - 1 \tag{6}$$

   For the cases in which the test value must not fall below the objective:

$$\text{Excursion}_i = \left(\frac{\text{Objective}_j}{\text{Failed test value}_i}\right) - 1 \tag{7}$$

2. The collective amount by which individual tests are out of compliance. This variable, referred to as the normalized sum of excursions, or nse, is calculated as:

$$\text{nse} = \frac{\sum_{i=1}^{n} \text{excursion}_i}{\text{Total number of tests}} \tag{8}$$

3. F_3 is then calculated by an asymptotic function that scales the normalized sum of the excursions from objectives (nse) to yield a range between 0 and 100.

$$F_3 = \left(\frac{\text{nse}}{0.01\text{nse} + 0.01}\right) \tag{9}$$

The CCME WQI is then calculated as:

$$\text{CCME WQI} = 100 - \left(\frac{\sqrt{{F_1}^2 + {F_2}^2 + {F_3}^2}}{1.732}\right) \tag{10}$$

The WQI values are then converted into rankings by using the index categorization scheme as presented in Table 5. The rankings range from poor to excellent based on the WQI scores.

The CCME WQI was developed to estimate the overall water quality status of Lake Nubia. Seven water quality parameters, measured and simulated (January 2006), have been used. These parameters are dissolved oxygen (mg/L), total dissolved solids (mg/L), nitrate–nitrite (mg/L), ammonium (mg/L), total phosphorus (mg/L), fecal coliform (colonies/100 mL), and pH (standard unit). The CCME WQI has been developed according to the Egyptian water quality standards for surface fresh waterways (objectives), decree No. 49 – Law 48/1982 – Article No. 60 amended in 2013 [48]; see Table 6.

For fecal coliform, as there is no Egyptian standard for it, the used objective was previously used by Heikal et al. [84].

Table 5 CCMEWQI categorization scheme [63]

Rank	CCME WQI Score	Description
Excellent	95–100	Water quality is protected with a virtual absence of threat or impairment; conditions very close to natural or pristine levels. These index values can only be obtained if all measurements are within objectives virtually all of the time
Good	80–94	Water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels
Fair	65–79	Water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels
Marginal	45–64	Water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels
Poor	0–44	Water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels

Table 6 Egyptian water quality standards for surface fresh waterways (objectives)

Parameter	DO (mg/L)	TDS (mg/L)	NO_3 (mg/L)	NH_4 (mg/L)	TP (mg/L)	FC (N/100 mL)	Ph (unit)
Objective	>6	<500	<2	<0.5	<2	<2,000	$6.5 < \ldots < 8.5$

3.4.3 Carlson TSI

The concept of trophic status is based on the fact that changes in nutrient levels (measured as total phosphorus) cause changes in algal biomass (measured as chlorophyll a) which in turn cause changes in lake clarity measured as Secchi disk transparency [165]. The Carlson TSI clearly represents this relationship. It offers the most suitable and acceptable method for trophic classifications of lakes [169]. The Carlson TSI is independently calculated from Secchi depth (SD), chlorophyll a concentration (CHL), and total phosphorus concentration (TP).

The Carlson TSI can be calculated by using one of the following equations [106, 200]:

$$\mathrm{TSI(SD)} = 60 - 14.41\ \ln[\mathrm{SD}\ (m)] \tag{11}$$

$$\mathrm{TSI(CHL)} = 9.81\ \ln[\mathrm{CHL}\ (\mu\mathrm{g/L})] + 30.6 \tag{12}$$

$$\mathrm{TSI(TP)} = 14.42\ \ln[\mathrm{TP}\ (\mu\mathrm{g/L})] + 4.15 \tag{13}$$

According to the TSI value, lakes or reservoirs can be trophically classified as one of the following classes:

- TSI < 40 oligotrophic
- 40–50 mesotrophic
- 50–70 eutrophic
- TSI > 70 hypereutrophic

If the three TSI values are not similar to each other, Pavluk and Vaate [165] return this to the possibilities that the algal growth may be light limited or nitrogen limited instead of phosphorus limited or, among other reasons, that the Secchi disk transparency is affected by erosional silt particles rather than by algae. They recommend using the average of TSI values as an indicator of the water trophic status in general.

The Carlson TSI was used to evaluate the trophic state of Lake Nubia. Two water quality parameters were used to estimate the Carlson TSI for 2006 and 2008 records: total phosphorus (μg/L) and chlorophyll a (μg/L). While for 2007 records, only one parameter was used, chlorophyll a (μg/L), as TP was not available. The Secchi depth was excluded because the lake transparency is affected by suspended particles rather than by algae; the southern part of AHD reservoir, Lake Nubia, has a high total suspended solid concentration.

3.4.4 LAWA TI

The German Regional Working Group on Water LAWA, Länderarbeitsgemeinschaft Wasser, has modified the OECD concept to develop a new trophic index which meets the current German conditions [144]. A data base of 117 reservoirs in Germany was used. The index depends on three parameters;

chlorophyll a (Chl-a), Secchi depth (SD), and total phosphorus (P_S for summer and P_F for spring). The LAWA TI depends on the parameter subindices, which should be calculated as follows [144, 201]:

$$\text{Index Chl-a} = 0.560 + 0.856\ \ln[\text{Chl-a}\ (\mu g/L)] \tag{14}$$

For other parameters subindices, the equations vary according to reservoir morphology. Deep reservoirs, with maximum water depth between 14 and 77.5 m, and parameter subindices are calculated as follows:

$$\text{Index SD} = 3.739 - 1.27\ln[\text{SD}\ (m)] \tag{15}$$

$$\text{Index } P_F = -0.155 + 0.813\ln[P_F\ (\mu g/L)] \tag{16}$$

$$\text{Index } P_S = -0.939 + 1.066\ln[P_S\ (\mu g/L)] \tag{17}$$

Consequently, the LAWA Total Index (LAWA TI) can be calculated as follows:

$$\begin{aligned}\text{LAWA TI} = {} & 0.939 + 0.285(\text{Index Chl-a}) - 0.301(\text{Index SD}) \\ & +0.136(\text{Index } P_F) + 0.249(\text{Index } P_S)\end{aligned} \tag{18}$$

For small reservoirs, maximum water depth < 13.5 m, parameters subindices are calculated as follows:

$$\text{Index SD} = 3.607 - 0.984\ln[\text{SD}\ (m)] \tag{19}$$

$$\text{Index } P_F = 0.014 + 0.803\ln[P_F\ (\mu g/L)] \tag{20}$$

$$\text{Index } P_S = 0.548 + 0.722\ln[P_S\ (\mu g/L)] \tag{21}$$

Then the LAWA Total Index (LAWA TI) can be calculated as follows:

$$\begin{aligned}\text{LAWA TI} = {} & 1.279 + 0.285(\text{Index Chl-a}) - 0.262(\text{Index SD}) \\ & + 0.134(\text{Index } P_F) + 0.168(\text{Index } P_S)\end{aligned} \tag{22}$$

If the parameters subindices values are not similar to each other, another flexible method of the LAWA TI calculation can be used, in which the irregular parameter subindex can be excluded. This method of calculation depends on parameter weight factors (Wf) according to Table 7.

Then LAWA TI can be calculated as follows:

$$\text{LAWA TI} = \frac{(\text{Index Chl-a})\text{Wf}_{\text{Chl}} + (\text{Index SD})\text{Wf}_{\text{SD}} + (\text{Index } P_F)\text{Wf}_{\text{PF}} + (\text{Index } P_S)\text{Wf}_{\text{PS}}}{\sum \text{Wf}} \tag{23}$$

According to LAWA TI value, lakes or reservoirs can be trophically classified as one of the following classes (Table 8).

Table 7 LAWA TI parameter weight factors

Parameter	Weight factor (Wf)
Chlorophyll a (Chl)	10
Secchi depth (SD)	8
Total phosphorus – spring (P_F)	5
Total phosphorus – summer (P_S)	7

Table 8 LAWA TI trophic status category

Deep reservoirs		Small reservoirs	
Trophic status	LAWA TI	Trophic status	LAWA TI
Oligotrophic	0.5–1.5	Eutrophic 1	2.6–3.0
Mesotrophic	1.6–2.5	Eutrophic 2	3.1–3.5
Eutrophic 1	2.6–3.0	Polytrophic 1	3.6–4.0
Eutrophic 2	3.1–3.5	Polytrophic 2	4.1–4.5
Polytrophic 1	3.6–4.0	Hypertrophic	4.6–5.0

As in Carlson TSI, two water quality parameters were used, total phosphorus (μg/L) and chlorophyll a (μg/L), for 2006 and 2008 records. While for 2007 records, only one parameter was used, chlorophyll a (μg/L), as TP was not available. Secchi depth was excluded because transparency is affected by suspended particles rather than by algae.

3.5 *Results and Discussions*

Four indices have been developed to evaluate the water quality and trophic status of the southern part of AHD reservoir (Lake Nubia) during low flood periods for 3 successive years: January 2006, February 2007, and March 2008. Two of these indices are the water quality indices NSF WQI and CCME WQI (described in the previous section). The other two indices are the trophic status indices Carlson TSI and LAWA TI. Ten control stations along Lake Nubia, Fig. 1, were chosen to evaluate the reservoir water quality.

3.5.1 NSF WQI

The measured water quality parameters were used to obtain NSF WQI. Figure 7 shows the longitudinal profiles of the developed NSF WQI along Lake Nubia at different stations for measured water quality parameters for 3 successive years. The results show that the water quality status of Lake Nubia, according to NSF WQI, is good. The water quality status of the reservoir varies spatially; NSF WQI increases from St. 2 to St. 9. This increase in the water quality returns to the decrease of water turbidity and fecal coliform concentration due to the change in the reservoir geometric properties. For 2008 longitudinal profile, a decrease in NSF WQI at

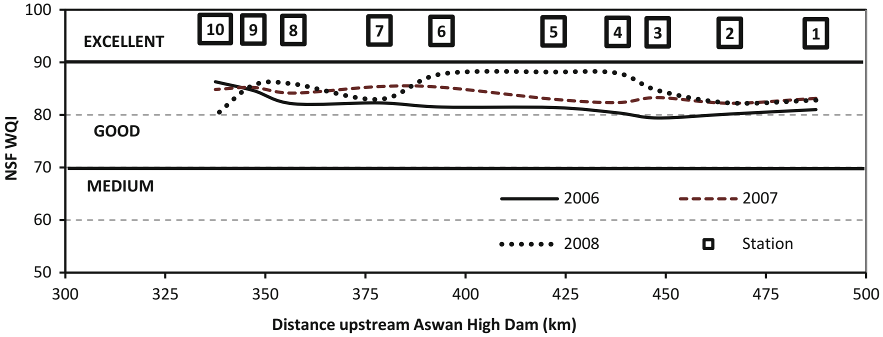

Fig. 7 Lake Nubia NSF WQI longitudinal profiles at different stations for measured water quality parameters during low flood periods, 2006–2008

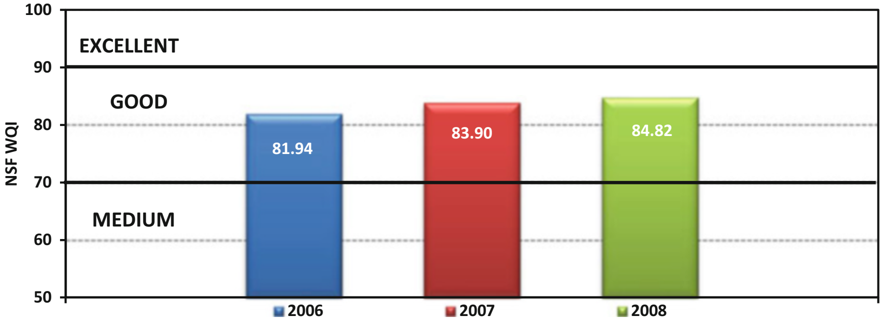

Fig. 8 Lake Nubia average NSF WQI for measured water quality parameters during low flood periods, 2006–2008

station 10 returns to increase in fecal coliform and pH and a decrease in DO concentrations. The average NSF WQI for the reservoir in low flood periods of 3 successive years can be seen in Fig. 8. It can be noticed that the average NSF WQI of 2008 is slightly greater than that of 2007, which in turn is slightly greater than that of 2006. These slight differences may return to the decrease in the flow (see Fig. 4).

3.5.2 CCME WQI

Figure 9 shows the overall CCME WQI of Lake Nubia for measured water quality parameters for 3 successive years, during low flood periods. The results show that the water quality status of the Lake Nubia is excellent for 2006 and 2007 and good for 2008. These results are based on the selected measured parameters and according to the Egyptian standards for surface fresh waterways. All measured water quality parameters values are in the objective range, for 2006 and 2007.

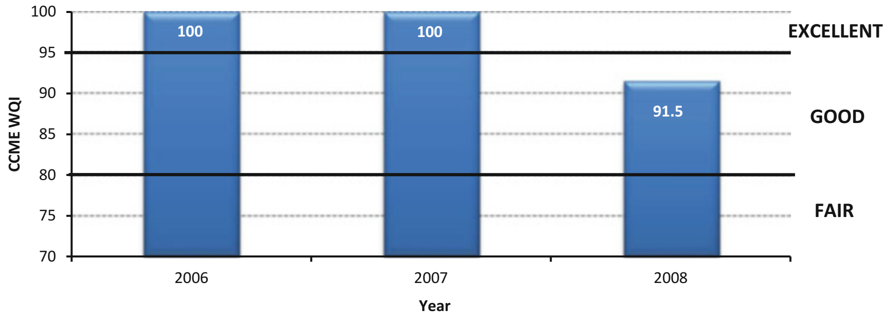

Fig. 9 Lake Nubia CCME WQI for measured water quality parameters during low flood periods, 2006–2008

While for 2008, CCME WQI is reduced as the measured records of pH were greater than the objectives at three different stations (St. 8, St. 9, and St. 10).

3.5.3 Carlson TSI

Figure 10 shows the Carlson TSI longitudinal profiles of Lake Nubia for measured total phosphorus only, January 2006 and March 2008. The results show that, according to Carlson TSI, the trophic state of Lake Nubia is hypereutrophic. The Carlson TSI varies spatially. This corresponds with the total phosphorus decrease due to increase of algae activity.

Lake Nubia Carlson TSI longitudinal profiles for measured chlorophyll a parameter only (January 2006, February 2007, and March 2008) are shown in Fig. 11. The results show that Lake Nubia trophic state, according to Carlson TSI, is almost eutrophic. The index slightly varies along Lake Nubia until station 8 where it starts to increase due to increase of algae activity.

The difference between Carlson TSI, based on total phosphorus, and that one based on chlorophyll a may return to phosphorus surplus in the water column [196]. This difference can be frequently noticed in reservoirs, in particular the riverine zone. For that it is recommended to use a comparative study (e.g., Carlson and LAWA), and both parameters (TP and Chl-a) should be used together (average) to estimate the trophic status of the reservoir.

Figures 12 and 13 show the average Carlson TSI longitudinal profiles of Lake Nubia for the measured water quality parameters in January 2006, February 2007, and March 2008. According to Carlson TSI, the Lake Nubia trophic state is eutrophic. For average Carlson TSI of February 2007, it can be noticed that it is clearly smaller than others, as it is based on one parameter only (Chl-a).

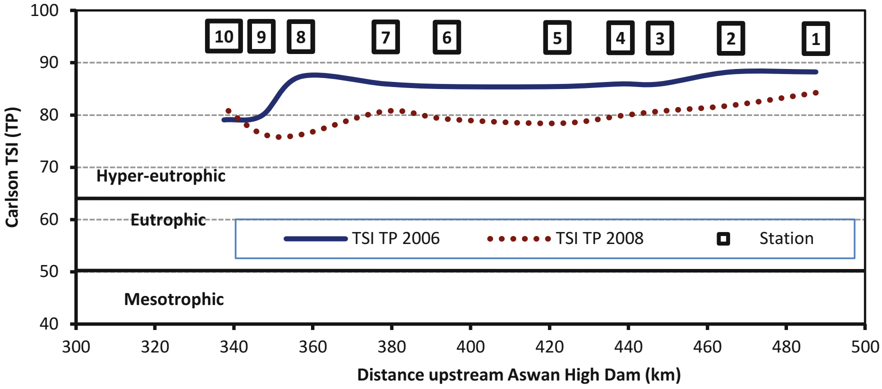

Fig. 10 Lake Nubia Carlson TSI longitudinal profiles for measured total phosphorus parameter during low flood periods in 2006 and 2008

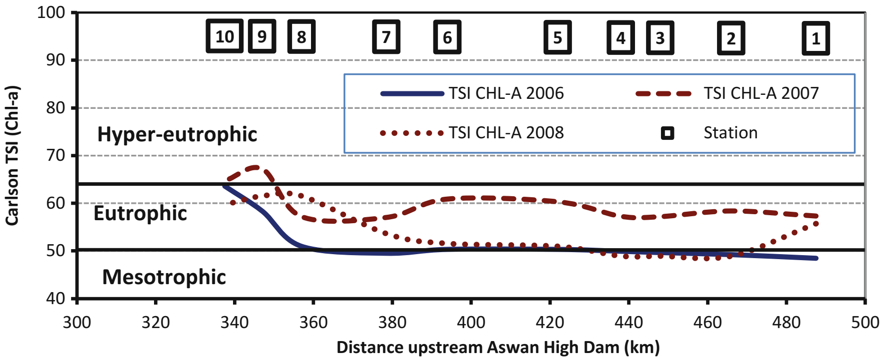

Fig. 11 Lake Nubia Carlson TSI longitudinal profiles for measured chlorophyll a parameter during low flood periods, 2006–2008

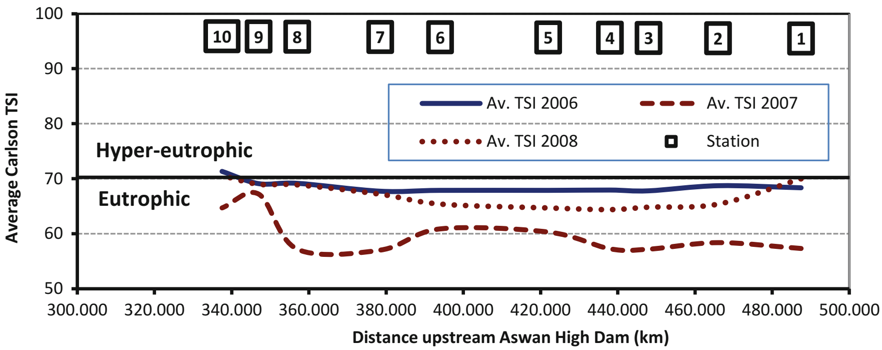

Fig. 12 Lake Nubia average Carlson TSI longitudinal profiles for measured water quality parameters during low flood periods, 2006–2008

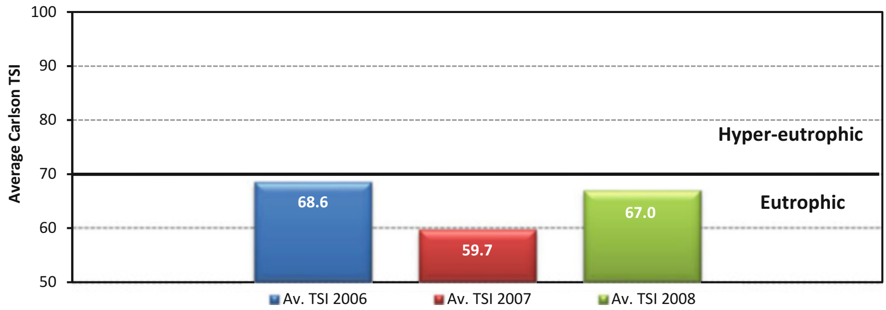

Fig. 13 Lake Nubia average Carlson TSI for measured water quality parameters during low flood periods, 2006–2008

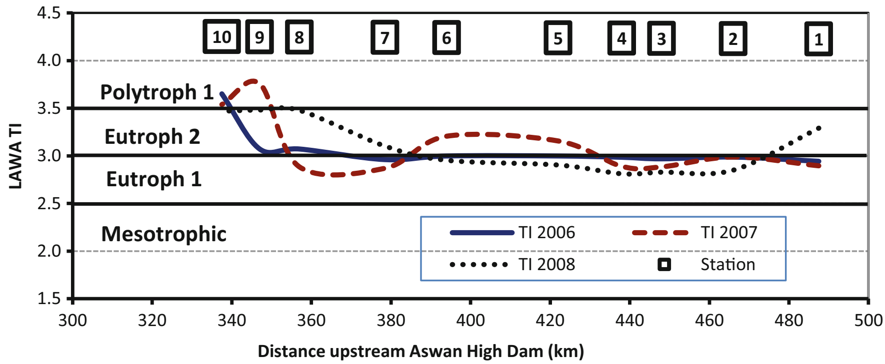

Fig. 14 Lake Nubia LAWA TI longitudinal profiles for measured water quality parameters during low flood periods, 2006–2008

3.5.4 LAWA TI

Figure 14 shows the Lake Nubia LAWA TI longitudinal profiles for measured parameters, January 2006. The results show that the Lake Nubia trophic state is eutrophic. The index slightly varies spatially until station 8 where it starts to increase due to algae activity.

The Lake Nubia average LAWA TI for measured water quality parameters, January 2006, February 2007, and March 2008, is shown in Fig. 15. According to LAWA TI, the Lake Nubia trophic state is eutrophic, and average LAWA TI is about 3.1. It can be noticed that, although average LAWA TI for February 2007 is based only on one parameter (Chl-a), the results do not differ much from others (comparing to Fig. 13). This may return to the flexibility design of this index which is mainly developed for reservoirs.

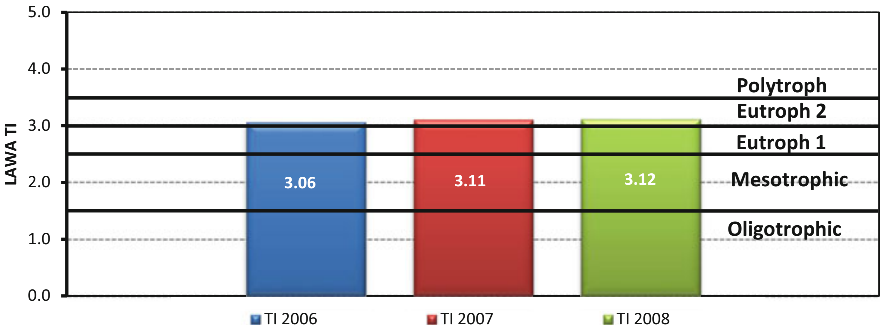

Fig. 15 Lake Nubia average LAWA TI for measured water quality parameters during low flood periods, 2006–2008

Table 9 A summary of average WQI and TSI study results for Lake Nubia during low-flow periods in 2006, 2007, and 2008

Year	Water quality indices (WQIs)		Trophic status indices (TSIs)	
	NSF WQI	CCME WQI	Carlson TSI	LAWA TI
2006 records	Good	Excellent	Eutrophic	Eutroph 2
	81.9 %	100 %	68.6	3.06
2007 records	Good	Excellent	Eutrophic	Eutroph 2
	83.9 %	100 %	59.7	3.11
2008 records	Good	Good	Eutrophic	Eutroph 2
	84.8 %	91.5 %	67	3.12

3.5.5 Results Summary

Table 9 summarizes the results of the application of the four water quality and trophic status indices for Lake Nubia during low flood periods, 2006–2008, based on the measured water quality characteristics.

3.6 Conclusions and Recommendations for Future Work

3.6.1 Conclusions

Two water quality indices, NSF WQI and CCME WQI, were developed to assess water quality state of the southern part of AHD reservoir, Lake Nubia, during low flood periods (January 2006, February 2007, and March 2008). Moreover, another two trophic status indices, Carlson TSI and LAWA TI, were developed to evaluate trophic status of Lake Nubia during the same periods.

1. According to the developed water quality indices results, Lake Nubia has a good water quality state during the low flood period. The modified CCME WQI, based on the measured data, indicates that the Lake Nubia water quality state ranges from excellent to good, according to the Egyptian water quality standards for surface fresh waterways.
2. Results of the applied trophic status indices show that the Lake Nubia trophic status is eutrophic. The Carlson TSI, based on total phosphorus, indicates that the trophic status of Lake Nubia is hypereutrophic.
3. The morphological characteristics of Lake Nubia affect water quality and trophic states of the reservoir; the transition zone of the reservoir (starts from St. 7) has a better water quality state and a somewhat worse trophic state than the riverine zone (upstream St. 7). This indicates that reservoir zones should be assigned to different water uses according to its water quality and trophic states.
4. For the AHD reservoir, Secchi depths should not be used to estimate the trophic status of the reservoir especially in the riverine and transitional zones where the water transparency is affected by suspended particles rather than by algae.

3.6.2 Recommendations for Future Work

1. A scientific study of the long-term trend of the water quality and trophic status should be performed for the AHD reservoir using a detailed database. Such a study could be the basis for a control management of the reservoir water quality.
2. Egyptian water quality standards for different uses (e.g., irrigation water, fishing, swimming) should be developed and used as guidelines in different water quality indices.
3. The NSF WQI should be developed according to different water uses instead of the general water quality state.
4. The CCME WQI procedure should have more guidelines about parameter choice and a more detailed ranking for the water quality state especially if all variables do not exceed the guidelines.
5. For trophic status indices, more than one parameter should be used. Moreover, a newer index should be developed for subtropical lakes and reservoirs such as the AHD reservoir.
6. As the trophic status is an aspect of water quality, a detailed study should be done to investigate the relation between water quality and trophic status indices.

Acknowledgements This research work was modified after the PhD work of the corresponding author. This PhD work was funded by the Egyptian government and conducted at the Leischtweiss Institute for Hydraulics and Water Resources (LWI), TU-Braunschweig, Germany. Providing the field data for this study by Nile Research Institute (NRI) and National Water Research Center (NWRC), Egypt, was greatly appreciated. The authors extremely thank the reviewers for their hard work to improve the quality of this chapter.

References

1. Boyacioglu H, Boyacioglu H (2007) Surface water quality assessment by environmetric methods. Environ Monit Assess 131:371–376
2. Cairns SH, Dickson KL, Atkinson SF (1997) An examination of measuring selected water quality trophic indicators with SPOT satellite HRV data. Society PE&RS:263–265
3. Camargo JA, Alonso A, de La Puente M (2005) Eutrophication downstream from small reservoirs in mountain rivers of Central Spain. Water Res 39:3376–3384
4. Debels P, Figueroa R, Urrutia R, Barra R, Niell X (2005) Evaluation of water quality in the Chillán River (Central Chile) using physicochemical parameters and a modified water quality index. Environ Monit Assess 110:301–322
5. Dodds W, Carney E, Angelo R (2006) Determining ecoregional reference conditions for nutrients, secchi depth and chlorophyll a in Kansas lakes and reservoirs. Lake Reserv Manag 22:151–159
6. Toufeek MAF, Korium MA (2009) Physicochemical characteristics of water quality in Lake Nasser water. Environ Res 3:141–148
7. Kung H, Ying L, Liu Y (1992) A complementary tool to water quality index: fuzzy clustering analysis. Water Resour Bull 28:525–533
8. Liou Y-T, Lo S-L (2005) A fuzzy index model for trophic status evaluation of reservoir waters. Water Res 39:1415–1423
9. Lu R-S, Lo S-L (2002) Diagnosing reservoir water quality using self-organizing maps and fuzzy theory. Water Res 36:2265–2274
10. Lu R-S, Lo S-L, Hu J-Y (1999) Analysis of reservoir water quality using fuzzy synthetic evaluation. Stoch Environ Res Risk Assess 13:327–336
11. Ocampo-Duque W, Ferré-Huguet N, Domingo JL, Schuhmacher M (2006) Assessing water quality in rivers with fuzzy inference systems: a case study. Environ Int 32:733–742
12. Ali MM, Murphy KJ, Abernethy VJ (1999) Macrophyte functional variables versus species assemblages as predictors of trophic status in flowing waters. Hydrobiologia 415:131–138
13. Andersen JH, Aroviita J, Carstensen J, Friberg N, Johnson RK, Kauppila P, Lindegarth M, Murray C, Norling K (2016) Approaches for integrated assessment of ecological and eutrophication status of surface waters in Nordic Countries. Ambio. doi:10.1007/s13280-016-0767-8
14. Azevêdo DJS, Barbosa JEL, Gomes WIA, Porto DE, Marques JC, Molozzi J (2015) Diversity measures in macroinvertebrate and zooplankton communities related to the trophic status of subtropical reservoirs: contradictory or complementary responses? Ecol Indic 50:135–149. doi:10.1016/j.ecolind.2014.10.010
15. Besse-Lototskaya A, Verdonschot PFM, Coste M, Van De Vijver B (2011) Evaluation of European diatom trophic indices. Ecol Indic 11:456–467. doi:10.1016/j.ecolind.2010.06.017
16. Bikbulatov ES, Stepanova IE (2002) Evaluation of the Rybinsk Reservoir trophic status using the potential of biogenic elements regeneration. Water Resour 29:665–670
17. Bonanno G, Lo Giudice R (2010) Application of two quality indices as monitoring and management tools of rivers. Case study: the Imera Meridionale River, Italy. Environ Manag 45:856–867
18. Cabezas A, Pallasch M, Schönfelder I, Gelbrecht J, Zak D (2014) Carbon, nitrogen, and phosphorus accumulation in novel ecosystems: Shallow lakes in degraded fen areas. Ecol Eng 66:63–71. doi:10.1016/j.ecoleng.2013.10.037
19. Chalar G, Arocena R, Pacheco JP, Fabián D (2011) Trophic assessment of streams in Uruguay: a trophic state index for benthic invertebrates (TSI-BI). Ecol Indic 11:362–369. doi:10.1016/j.ecolind.2010.06.004
20. Dhib A, Denis M, Barani A, Turki S, Aleya L (2016) Ultra- and microplankton assemblages as indicators of trophic status in a Mediterranean lagoon. Ecol Indic 64:59–71. doi:10.1016/j.ecolind.2015.12.032

21. El-Shabrawy GM, Germoush MOA (2014) Seasonal changes and abundance of rotifers in a shallow Manzalah lake (Egypt). Ecohydrol Hydrobiol 14:243–252. doi:10.1016/j.ecohyd.2014.06.001
22. Fremling CR, Johnson DK (1990) Recurrence of Hexagenia mayflies demonstrates improved water quality in Pool 2 and Lake Pepin, Upper Mississippi River. In: Campbell IC (ed) Mayflies and stoneflies. Springer Netherlands, pp 243–248
23. Guo L, Hu Z, Fang F, Liu T, Chuai X, Yang L (2014) Trophic status determines the nirS-denitrifier community in shallow freshwater lakes. Ann Microbiol 64:999–1006. doi:10.1007/s13213-013-0737-3
24. Huszar VLM, Silva LHS, Domingos P, Marinho M, Melo S (1998) Phytoplankton species composition is more sensitive than OECD criteria to the trophic status of three Brazilian tropical lakes. Hydrobiologia 369(370):59–71
25. Mermillod-Blondin F, Foulquier A, Maazouzi C, Navel S, Negrutiu Y, Vienney A, Simon L, Marmonier P (2013) Ecological assessment of groundwater trophic status by using artificial substrates to monitor biofilm growth and activity. Ecol Indic 25:230–238. doi:10.1016/j.ecolind.2012.09.026
26. Nuernberg GK (1996) Trophic state of clear and colored, soft-and hardwater lakes with special consideration of nutrients, anoxia, phytoplankton and fish. Lake Reserv Manag 12:432–447
27. Peng L (2004) A universal index formula suitable to multiparameter water quality evaluation. Numer Methods Partial Diff Equ 20:368–373
28. Poikane S, Birk S, Böhmer J, Carvalho L, De Hoyos C, Gassner H, Hellsten S, Kelly M, Lyche Solheim A, Olin M, Pall K, Phillips G, Portielje R, Ritterbusch D, Sandin L, Schartau AK, Solimini AG, Van Den Berg M, Wolfram G, Van De Bund W (2015) A hitchhiker's guide to European lake ecological assessment and intercalibration. Ecol Indic 52:533–544. doi:10.1016/j.ecolind.2015.01.005
29. Qin BQ, Gao G, Zhu GW, Zhang YL, Song YZ, Tang XM, Xu H, Deng JM (2013) Lake eutrophication and its ecosystem response. Chin Sci Bull 58:961–970. doi:10.1007/s11434-012-5560-x
30. Rendón-Von Osten J, Memije MG, Ortiz A, Soares AMVM, Guilhermino L (2006) An integrated approach to assess water quality and environmental contamination in the fluvial-lagoon system of the Palizada River, Mexico. Environ Toxicol Chem 25:3024–3034
31. Schulz HK, Śmietana P, Schulz R (2006) Estimating the human impact on populations of the endangered noble crayfish (Astacus astacus L.) in north-western Poland. Aquat Conserv 16:223–233. doi:10.1002/aqc.726
32. Viaroli P, Christian RR (2003) Description of trophic status, hyperautotrophy and dystrophy of a coastal lagoon through a potential oxygen production and consumption index—TOSI: Trophic Oxygen Status Index. Ecol Indic 3:237–250
33. Yang B, Jiang Y-J, He W, Liu W-X, Kong X-Z, Jørgensen SE, Xu F-L (2016) The tempo-spatial variations of phytoplankton diversities and their correlation with trophic state levels in a large eutrophic Chinese lake. Ecol Indic 66:153–162. doi:10.1016/j.ecolind.2016.01.013
34. Ott WR (1978) Water quality indices: a survey of indices used in the United States. EPA
35. Abbasi SA (2002) Water quality indices, state of the art INCOH. National Institute of Hydrology, Roorkee
36. Horton RK (1965) An index number system for rating water quality. J Water Pollut Control Fed 37:300–306
37. Abbasi T, Abbasi SA (2012) Water quality indices. Elsevier Science, Amsterdam
38. Asadollahfardi G (2015) Water quality management: assessment and interpretation. doi:10.1007/978-3-662-44725-3
39. Poonam T, Tanushree B, Sukalyan C (2013) Water quality indices – important tools for water quality assessment. Int J Adv Chem 1:15–28

40. Ribeiro Alves MT, Barreto Teresa F, Nabout JC (2014) A global scientific literature of research on water quality indices: trends, biases and future directions. Acta Limnol Bras 26:245–253. doi:10.1590/S2179-975X2014000300004
41. Sutadian AD, Muttil N, Yilmaz AG, Perera BJC (2016) Development of river water quality indices – a review. Environ Monit Assess 188:1–29. doi:10.1007/s10661-015-5050-0
42. Walsh P, Wheeler W (2012) Water quality index aggregation and cost benefit analysis
43. Gharib SM, El-sherif ZM, Abdel-halim AM, Radwan AA (2011) Phytoplankton and environmental variables as a water quality indicator for the beaches at Mediterranean Sea, Egypt: an assessment. Oceanologia 53:819–836. doi:10.5697/oc.53-3.819
44. Ezzat SM, Elkorashey RM (2012) Omar Bek drain water quality and its impact on Damietta Branch, River Nile-Egypt. American-Eurasian J Agric Environ Sci 12:472–483
45. Hassanein NM, El-Baghdady KZ, Farid AK, Tawfik TA, Ewida AY (2012) Microbial communities and water quality of some groundwater systems in Egypt. Egypt J Exp Biol (Bot) 8:25–42
46. Fathy SAH, Abdel Hamid FF, Shreadah MA, Mohamed LA, El-Gazar MG (2012) Application of principal component analysis for developing water quality index for selected coastal areas of Alexandria Egypt. Resour Environ 2:297–305. doi:10.5923/j.re.20120206.08
47. Omran E-sE (2012) A proposed model to assess and map irrigation water well suitability using geospatial analysis. Water 4:545–567. doi:10.3390/w4030545
48. Agrama AA, El-Sayed EA (2013) Assessessing and mapping water quality (case study: western delta -Egypt). Int Water Technol J 3:159–170
49. Goher ME, Hassan AM, Abdel-Moniem IA, Fahmy AH, El-Sayed SM (2014) Evaluation of surface water quality and heavy metal indices of Ismailia Canal, Nile River, Egypt. Egyptian J Aquat Res 40:225–233. doi:10.1016/j.ejar.2014.09.001
50. Omran E-sE, Ghallab A, Selmy S, Gad A-a (2014) Evaluation and mapping water wells suitability for irrigation using GIS in Darb El-Arbaein, South Western Desert, Egypt National Authority for Remote Sensing and Space Science, Cairo, Egypt. Int J Water Resour Arid Environ 3:63–76
51. Abdullah AM, Hussona SE-D (2014) Water quality assessment of Mahmoudia Canal in Northern West of Egypt. J Pollut Eff Control 02. doi:10.4172/2375-4397.1000121
52. Khalil MM (2014) Impact of power plants outlet on Nile River Water Quality “Case study: El-Kurimat Power Plant, Egypt”. Int J Adv Res 2:711–720
53. Shaltout NA, Abd-El-Khalek DE (2014) Assessment of seawater quality of El-Dekhaila Harbor, Alexandria. Asian J Adv Basic Sci 3:206–216
54. Shreadah MA, Masoud MS, Khattab A-RM, Zokm GME (2014) Impacts of different drains on the seawater quality of El-Mex bay (Alexandria, Egypt). J Ecol Nat Environ 8:287–303. doi:10.5897/JENE2014.0465
55. Abdullah AM (2014) Effect of Omumm Water Drainage on Noubaria Canal Water Quality and Alexandria drinking water treatments plants. J Pollut Eff Control 02. doi:10.4172/2375-4397.1000118
56. Armanuos A, Negm A, Valeriano OCS (2015) Groundwater quality investigation using water quality index and Arcgis: case study: Western Nile Delta Aquifer. In: Eighteenth International Water Technology Conference (IWTC18), Sharm ElSheikh, Egypt. doi:10.13140/RG.2.1.2675.6641
57. El-amier YA, Zahran MAE-k, Al-mamory SH (2015) Assessment the physico-chemical characteristics of water and sediment in Rosetta Branch, Egypt. J Water Resour Prot 7:1075–1086
58. Abukila AF (2015) Assessing the drain estuaries’ water quality in response to pollution abatement. Water Sci 29:1–18. doi:10.1016/j.wsj.2015.02.002
59. Reda A, Riad PHS, Gammal HAE, El-razik MHA, Deen MMNE, Khalifa AAM (2015) Water quality management information system upstream Cairo drinking water plants. Danish J Eng Appl Sci:14–29

60. Allam A, Fleifle A, Tawfik A, Yoshimura C, El-Saadi A (2015) A simulation-based suitability index of the quality and quantity of agricultural drainage water for reuse in irrigation. Sci Total Environ 536:79–90. doi:10.1016/j.scitotenv.2015.07.029
61. Tahlawi MRE, Kassem MA-e, Baghdadi GY, Saleem HA (2016) Estimating and plotting of groundwater quality using WQI UA and GIS in Assiut Governorate, Egypt. World J Eng Technol 4:59–70
62. Brown RM, Mcclelland NI, Deininger RA, Tozer RG (1970) A water quality index. Do we dare? Water Sewage Works 117:339–343
63. CCME (2001) Canadian water quality guidelines for the protection of aquatic life. CCME water quality index 1.0 Technical Report. Canadian Council of Ministers of the Environment
64. Deininger R (1980) A water quality index for rivers. Water Int 5:16–21
65. Dinius SH (1987) Design of an index of water quality. J Am Water Resour Assoc 23:833–843
66. House MA (1990) Water quality indices as indicators of ecosystem change. Environ Monit Assess 15:255–263
67. House MA (1989) A water quality index for river management. Water Environ J 3:336–344
68. Kaurish FW, Younos T (2007) Developing a standardized water quality index for evaluating surface water quality. J Am Water Resour Assoc 43:533–545
69. Liou S-M, Lo S-L, Wang S-H (2004) A generalized water quality index for Taiwan. Environ Monit Assess 96:35–52
70. Said A, Stevens DK, Sehlke G (2004) An innovative index for evaluating water quality in streams. Environ Manag 34:406–414
71. Sarkar C, Abbasi SA (2006) Qualidex – a new software for generating water quality indices. Environ Monit Assess 119:201–231
72. Smith DG (1990) A better water quality indexing system for rivers and streams. Water Res 24:1237–1244
73. Steinhart CE, Schierow LJ, Sonzogni WC (1982) An environmental quality index for the Great Lakes. Water Resour Bull 18:1025–1031
74. Mamun AA, Hafizah SN, Alam MZ, Islamic I, Gombak J (2009) Improvement of existing water quality index in Selangor, Malaysia. 2nd International Conference on Water & Flood Management (ICWFM)
75. Coletti C, Testezlaf R, Ribeiro TAP, de Souza RTG, de A Pereira D (2010) Water quality index using multivariate factorial analysis. Revista Brasileira de Engenharia Agrícola e Ambiental 14:517–522. doi:10.1590/S1415-43662010000500009
76. Nikoo MR, Kerachian R, Malakpour-Estalaki S, Bashi-Azghadi SN, Azimi-Ghadikolaee MM (2011) A probabilistic water quality index for river water quality assessment: a case study. Environ Monit Assess 181:465–478. doi:10.1007/s10661-010-1842-4
77. Taner MU, Üstün B, Erdinçlera A (2011) A simple tool for the assessment of water quality in polluted lagoon systems: a case study for Küçükçekmece Lagoon, Turkey. Ecol Indic 11:749–756. doi:10.1016/j.ecolind.2010.08.003
78. Lobato TC, Hauser-Davis RA, Oliveira TF, Silveira AM, Silva HAN, Tavares MRM, Saraiva ACF (2015) Construction of a novel water quality index and quality indicator for reservoir water quality evaluation: a case study in the Amazon region. J Hydrol 522:674–683. doi:10.1016/j.jhydrol.2015.01.021
79. Sikder MT, Tanaka S, Saito T, Hosokawa T (2015) Vulnerability assessment of surface water quality with an innovative integrated multi-parameter water quality index (IMWQI). Pollution 1:333–346
80. Whittaker G, Barnhart B, Färe R, Grosskopf S (2015) Application of index number theory to the construction of a water quality index: aggregated nutrient loadings related to the areal extent of hypoxia in the northern Gulf of Mexico. Ecol Indic 49:162–168. doi:10.1016/j.ecolind.2014.10.003
81. Abdel Rehim SS, Abdel Bari MR, Khalil MM, Heikal MT, Salem TA (2002) Impact of heat on the physical and chemical properties of Lake Nasser water. J Environ Sci 5:325–349

82. Chaturvedi MK, Bassin JK (2010) Assessing the water quality index of water treatment plant and bore wells, in Delhi, India. Environ Monit Assess 449–453. doi:10.1007/s10661-009-0848-2
83. Effendi H, Wardiatno Y (2015) Water quality status of Ciambulawung River, Banten Province, based on pollution index and NSF-WQI. Proc Environ Sci 24:228–237. doi:10.1016/j.proenv.2015.03.030
84. Heikal MT, El-Sherbini A, Salem TA, Yousry MM (2007) Temporal and spatial variation of water quality parameters along the River Nile. In: NAWQAM Final Conference on Egypt Paradigm in Integrated Water Resources Management, 17–19 February, Sharm El Sheikh, Egypt, p 21
85. Rajankar PN, Gulhane SR, Tambekar DH, Ramteke DS, Wate SR, Impact E, Division RA (2009) Water quality assessment of groundwater resources in Nagpur Region (India) based on WQI. E J Chem 6:905–908
86. Ionus O (2010) Water quality index – assessment method of the Motru River Water Quality (Oltenia, Romania) Indicele De Calitate a Apei – Metod Ă De Determinare a Calit Ăţ Ii Apei Râului Motru (Oltenia, România) 13:74–83
87. Sharma MP, Sharma S, Gael V, Sharma P, Kumar A (2006) Water quality assessment of Behta River using benthic macroinvertebrates. Life Sci J 3
88. Varnosfaderany MN, Mirghaffary N, Ebrahimi E, Soffianian A (2009) Water quality assessment in an arid region using a water quality index. Water Sci Technol 60:2319–2327
89. Wills M, Irvine KN (1996) Application of the national sanitation foundation water quality index in the cazenovia creek, NY, pilot watershed management project. Middle States Geogr:95–104
90. Boyacioglu HI (2010) Utilization of the water quality index method as a classification tool. Environ Monit Assess 167:115–124. doi:10.1007/s10661-009-1035-1
91. CCME (2004) CCME National Water Quality Index Workshop. Water. CCME
92. Donia NS, Farag HA (2010) A waste load model analysis for El Noubariya Canal Drinking Water Abstraction, Egypt 2. Description of El-Noubariya Canal. In: Fourteenth International Water Technology Conference (IWTC 14), 2010, Cairo, Egypt. IWTC, pp 675–690
93. Ed Quilty QE (2003) Water quality objectives attainment monitoring Fraser river tributaries from Hope to Kanaka Creek 2002. Environmental protection. Ministry of Water, Land & Air Protection Lower Mainland Region
94. Heuvel MRVD (2009) Site specific guidelines for phosphorus in relation to the water quality index calculations for Prince Edward Island, p 35
95. Hurley T, Sadiq R, Mazumder A (2012) Adaptation and evaluation of the Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) for use as an effective tool to characterize drinking source water quality. Water Res 46:3544–3552. doi:10.1016/j.watres.2012.03.061
96. Lumb A, Halliwell D, Sharma T (2006) Application of CCME water quality index to monitor water quality: a case study of the Mackenzie River Basin, Canada. Environ Monit Assess 113:411–429
97. Mercier V, Fox D, Khan H, Taylor D, Raymond B, Bond W, Caux P-Y (2005) Application and testing of the water quality index in Atlantic Canada – report summary. CCME, Atlantic
98. Radwan M (2005) Evaluation of different water quality parameters for the Nile River and the different drains. In: Ninth International Water Technology Conference, Sharm El-Sheikh, Egypt, pp 1293–1303
99. Selvam S, Manimaran G, Sivasubramanian P, Balasubramanian N, Seshunarayana T (2014) GIS-based evaluation of water quality index of groundwater resources around Tuticorin coastal city, south India. Environ Earth Sci 71:2847–2867. doi:10.1007/s12665-013-2662-y
100. Khan AA, Abdel-Gawad S, Khan H (2008) A real time water quality monitoring network and water quality indices for River Nile. In: 13th IWRA world water congress, 1–4 September, Montpellier, France, p 15

101. de Rosemond S, Duro DC, Dubé M (2009) Comparative analysis of regional water quality in Canada using the water quality index. Environ Monit Assess 156:223–240
102. Mojahedi SA, Attari J (2009) A comparative study of water quality indices for Karun River. In: Proceedings of World Environmental and Water Resources Congress 2009, Great Rivers. Asce
103. Boyacioglu H (2010) Utilization of the water quality index method as a classification tool. Environ Monit Assess 167:115–124
104. Bhatti MT, Latif M (2009) Assessment of water quality of a river using an indexing approach during the low-flow season. Irrigation Drainage 60:103–114
105. Ryding S-O, Rast W (1989) The control of eutrophication of lakes and reservoirs, vol 1: Man and the biosphere series. UNESCO and Parthenon Publishing Group, Paris
106. Carlson RE (1977) A trophic state index for lakes. Limnol Oceanogr 22(2):361–369
107. Arfi R (2003) The effects of climate and hydrology on the trophic status of Selingue Reservoir, Mali, West Africa. Lake Reserv Res Manag 8:247–257
108. Barnwal P, Mishra S, Singhal SK (2015) Risk assessment and analysis of water quality in Ramgarh Lake, India. J Integr Sci Technol 3:22–27
109. Chang CL, Liu HC (2015) Applying the Back-Propagation Neural Network model and fuzzy classification to evaluate the trophic status of a reservoir system. Environ Monit Assess 187:567. doi:10.1007/s10661-015-4513-7
110. Gupta I, Kumar A, Singh C, Kumar R (2015) Detection and mapping of water quality variation in the Godavari River using water quality index, clustering and GIS techniques. J Geogr Inf Syst 7:71–84
111. Hassan AA (2000) Evaluation of the eutrophication status in the southern part of Lake Manzala, Egypt. Sci Bull Fac Eng Ain Shams Univ 35(1):155–173
112. Koussouris T, Diapoulis A, Bertahas I, Photis G (1991) Evaluating trophic status and restoration procedures of a polluted lake, Lake Kastoria, Greece. GeoJournal 23:153–161
113. Mullins ML, Whisenant AS (2004) Somerville reservoir water quality study, vol WQTS-2004-02. Texas Parks and Wildlife Department, Austin
114. Thiemann S, Kaufmann H (2000) Determination of chlorophyll content and trophic state of lakes using field spectrometer and IRS-1C satellite data in the Mecklenburg Lake District, Germany. Remote Sens Environ 73:227–235
115. Galloway JM, Green WR (2004) Water-quality assessment of lakes Maumelle and Winona, Arkansas, 1991 through 2003. Scientific Investigations vol Report 2004-5182. U.S. Department of the Interior, U.S. Geological Survey
116. Santhanam H, Amal Raj S (2010) Carlson's Index, a poor cursor of trophic status assessment of Pulicat Lagoon, southeast coast of India. Int J Environ Stud 67:17–25
117. Ahmed M, Aly A, Hussien R (2013) Human-induced and eutrophication impacts on physio-chemical and isotopic water characteristics of a Northeastern Nile Delta Lake, Egypt. Arab J Nucl Sci Appl 46:1–17
118. Ahmed M, Donia N, Fahmy M (2006) Eutrophication assessment of Lake Manzala, Egypt using geographical information systems (GIS) techniques. J Hydroinf:101–109. doi:10.2166/hydro.2006.014
119. Donia N, Hussein M (2004) Eutrophication assessment of Lake Manzala using GIS techniques. In: Eighth International Water Technology Conference (IWTC8), Alexandria, Egypt
120. Das Gupta A, Sarkar S, Ghosh P, Saha T, Sil AK (2016) Phosphorous dynamics of the aquatic system constitutes an important axis for waste water purification in natural treatment pond (s) in East Kolkata Wetlands. Ecol Eng 90:63–67. doi:http://dx.doi.org/10.1016/j.ecoleng.2016.01.056
121. Brezonik PL (1984) Trophic state indices: rationale for multivariate approaches. Lake Reserv Manag 1:441–445. doi:10.1080/07438148409354553
122. Kratzer C, Brezonik PL (1981) A carlson-type trophic state index for nitrogen in Florida lakes. J Am Water Resour Assoc 17(4):713–715

123. Ganguly D, Patra S, Muduli PR, Vardhan KV (2015) Influence of nutrient input on the trophic state. 1005–1017
124. Saghi H, Karimi L, Javid AH (2015) Investigation on trophic state index by artificial neural networks (case study: Dez Dam of Iran). Appl Water Sci:127–136. doi:10.1007/s13201-014-0161-2
125. Fachbereichsstandard (1982) Nutzung und Schutz der Gewässer. Stehende Binnengewässer. Klassifizierung. vol TGL 27885/01 Ministerium für Umweltschutz und Wasserwirtschaft
126. OECD (1982) Eutrophication of waters: monitoring, assessment and control. Organisation for Economic Co-operation and Development Paris
127. Sigee DC (2005) Freshwater microbiology: biodiversity and dynamic interactions of micro-organisms in the aquatic environment. Wiley, Hoboken
128. Dasí M, Miracle M, Camacho A, Soria J, Vicente E (1998) Summer phytoplankton assemblages across trophic gradients in hard-water reservoirs. Hydrobiologia:27–43
129. Kasprzak P, Gervais F, Adrian R, Weiler W, Radke R, Jäger I, Riest S, Siedel U, Schneider B, Böhme M, Eckmann R, Walz N (2000) Trophic characterization, Pelagic Food Web Structure and comparison of two mesotrophic lakes in Brandenburg (Germany). Int Rev Hydrobiol 85:167–189
130. Lugliè A, Aktan Y, Casiddu P, Sechi N (2001) The trophic status of Bidighinzu Reservoir (Sardinia) before and after the diversion of waste waters. J Limnol 60:135–142
131. Markogianni V, Dimitriou E, Karaouzas I (2014) Water quality monitoring and assessment of an urban Mediterranean lake facilitated by remote sensing applications. Environ Monit Assess 186:5009–5026. doi:10.1007/s10661-014-3755-0
132. Schrenk-bergt C, Krause D, Prawitt O, Lewandowski J (2002) Eutrophication problems and their potential solutions in the artificial shallow lake Altmühlsee. Freshwater Biol 21:73–86
133. Vollenweider RA, Giovanardi F, Montanari G, Rinaldi A (1998) Characterization of the trophic conditions of marine coastal waters with special reference to the NW Adriatic Sea: proposal for a trophic scale, turbidity and generalized water quality index. Environmetrics 9:329–357. doi:10.1002/(SICI)1099-095X(199805/06)9:3<329::AID-ENV308>3.0.CO;2-9
134. Balkis N, Toklu-Aliçli B, Balci M (2012) Evaluation of ecological quality status with the trophic index (TRIX) values in the coastal waters of the Gulfs of Erdek and Bandirma in the Marmara Sea. CdnIntechopenCom
135. Chen Y, Niu Z, Zhang H (2013) Eutrophication assessment and management methodology of multiple pollution sources of a landscape lake in North China. Environ Sci Pollut Res 20:3877–3889. doi:10.1007/s11356-012-1331-0
136. Christia C, Giordani G, Papastergiadou E (2014) Assessment of ecological quality of coastal lagoons with a combination of phytobenthic and water quality indices. Mar Pollut Bull 86:411–423. doi:10.1016/j.marpolbul.2014.06.038
137. Pavlidou A, Simboura N, Rousselaki E, Tsapakis M, Pagou K, Drakopoulou P, Assimakopoulou G, Kontoyiannis H, Panayotidis P (2015) Methods of eutrophication assessment in the context of the water framework directive: examples from the Eastern Mediterranean coastal areas. Cont Shelf Res 108:156–168. doi:10.1016/j.csr.2015.05.013
138. Primpas I, Karydis M (2011) Scaling the trophic index (TRIX) in oligotrophic marine environments. Environ Monit Assess 178:257–269. doi:10.1007/s10661-010-1687-x
139. Vargas-González HH, Arreola-Lizárraga JA, Mendoza-Salgado RA, Méndez-Rodriguez LC, Lechuga-Deveze CH, Padilla-Arredondo G, Cordoba-Matson M (2014) Effects of sewage discharge on trophic state and water quality in a coastal ecosystem of the Gulf of California. ScientificWorldJournal 2014:7
140. Zoriasatein N, Jalili S, Poor F (2013) Evaluation of ecological quality status with the trophic index (TRIX) values in coastal area of Arvand, Northeastern of Persian Gulf, Iran. World J Fish Mar Sci 5:257–262. doi:10.5829/idosi.wjfms.2013.05.03.7297
141. Burns NM, Rutherford JC, Clayton JS (1999) A monitoring and classification system for New Zealand lakes and reservoirs. Lake Reserv Manag 15:255–271. doi:10.1080/07438149909354122

142. Eccles A (2015) A trophic state analysis of selected water bodies in Grand Teton National Park. Brigham Young University, Provo
143. Xiang B, Song J-w, Wang X-y, Zhen J (2015) Improving the accuracy of estimation of eutrophication state index using a remote sensing data-driven method: a case study of Chaohu Lake, China. Water SA 41:753–761
144. LAWA (2001) Gewässerbewertung – Stehende Gewässer. Vorläufige Richtlinie für die Trophieklassifikation von Talsperren. LAWA, Schwerin
145. Ackermann G, Loth P, Sudbrack R (2005) Abschätzung des ökologischen Potenzials von Talsperren nach der Trophie. Universität Duisburg-Essen Freistaat
146. Schöpfer C, Björnsen G, Dietze M, Schimrosczyk J (2007) Nachhaltige Bewirtschaftung des Rappbodetalsperren- systems im Ostharz. In: 14. Deutsches Talsperrensymposium in Freising, 2007 "Talsperren in Europa – Aufgaben und Herausforderungen", Freising, Germany, 2007. DTK, pp 436–442
147. Ruhrverband (2008) Talsperren-Fischerei Jahresbericht 2007. Ruhrverband
148. HLUG (2008) Hessisches Gütemessprogramm Seenuntersuchungen 2007. Hessisches Landesamt für Umwelt und Geologie
149. Scharf W (2008) The use of nutrient reduction and food-web management to improve water quality in the deep stratifying Wupper Reservoir, Germany. Hydrobiologia 603:105–115
150. Thornton J, Steel A, Rast W (1996) Reservoirs. In: Chapman DV (ed) Water quality assessments: a guide to the use of biota, sediments and water in environmental monitoring. Spon, London
151. Lind OT, Terrell TT, Kimmel BL (1993) Problems in reservoir trophic-state classification and implications for reservoir management. In: Straškraba M, Tundisi JG, Duncan A (eds) Comparative reservoir limnology and water quality management. Developments in hydrobiology, vol 77. Kluwer Academic, Dordrecht, p 291
152. Cunha DGF, Calijuri MC, Lamparelli MC (2013) A trophic state index for tropical/subtropical reservoirs (TSItsr). Ecol Eng 60:126–134. doi:10.1016/j.ecoleng.2013.07.058
153. Lamparelli M (2004) Graus de trofia em corpos d'água do Estado de São Paulo: Avaliação dos métodos de monitoramento
154. Salas H, Martino P (1991) A simplified phosphorus trophic state model for warm-water tropical lakes. Water Res 25:341–350. doi:10.1016/0043-1354(91)90015-I
155. Cigagna C, Marcos D, Antonio B, Camargo FM, Sturaro R (2016) Trophic state index (TSI) and physico-chemical characteristics of a shallow reservoir in southeast Brazil. Environ Earth Sci 75. doi:10.1007/s12665-015-4951-0
156. de Souza Beghelli FG, Frascareli D, Pompêo MLM, Moschini-Carlos V (2016) Trophic state evolution over 15 years in a tropical reservoir with low nitrogen concentrations and cyanobacteria predominance. Water Air Soil Pollut 227:95. doi:10.1007/s11270-016-2795-1
157. Buetow D (2008) 2007 Lake Monitoring Report – Mecklenburg County Water Quality Program SWIM Phase I Part 2-CO – Final Report for FY2007–2008
158. Cudowski A (2015) Dissolved reactive manganese as a new index determining the trophic status of limnic waters. Ecol Indic 48:721–727. doi:10.1016/j.ecolind.2014.09.035
159. Dunalska JA (2011) Total organic carbon as a new index for monitoring trophic states in lakes. Oceanol Hydrobiol Stud 40:112–115. doi:10.2478/s13545-011-0022-7
160. Gupta M (2014) A new trophic state index for lagoons. J Ecosyst 2014:1–8. doi:10.1155/2014/152473
161. Huo S, Ma C, Xi B, Su J, Zan F, Ji D, He Z (2013) Establishing eutrophication assessment standards for four lake regions, China. J Environ Sci (China) 25:2014–2022. doi:10.1016/S1001-0742(12)60250-2
162. Nalamutt TD, Karmakar S (2014) Modeling impreciseness of trophic state levels for eutrophication assessment. J Clean Energy Technol 2:140–144. doi:10.7763/JOCET.2014.V2.109
163. Novo E, Lobo F, Calijuri MDC, Tundisi J (1994) Predictive modeling of trophic status of a tropical reservoir using geographical information systems. Geosci Remote:1207–1210

164. O'Boyle S, McDermott G, Noklegaard T, Wilkes R (2013) A simple index of trophic status in Estuaries and Coastal bays based on measurements of pH and dissolved oxygen. Estuaries Coast 36:158–173. doi:10.1007/s12237-012-9553-4
165. Pavluk T, Vaate A (2008) Trophic index and efficiency. In: Jørgensen SE, Fath BD (eds) Encyclopedia of ecology, vol 5, 1st edn. Elsevier, Oxford, pp 3602–3608
166. Peng X, Kang S, Zhang L, Zhang Y, Hu D, Yao W (2009) The assessment of the eutrophication status and analysis on the main controlling factor of Erlongshan Reservoir. In: International Conference on Environmental Science and Information Application Technology, pp 120–123
167. Salas HJ, Martino P (1989) Simplified methodologies for the evaluation of eutrophication in warm – water tropical lakes. WHO, Pan American Health Organization, Environmental Health Program, Warsaw
168. Seisdedo M, Herrera R, Arencibia G (2013) Index for assessing water trophic status in semi-enclosed Cuban bays. Case study: Cienfuegos Bay
169. Xu F-L (2008) Trophic classification for lakes. In: Jørgensen SE, Fath BD (eds) Encyclopedia of ecology, vol 5, 1st edn. Elsevier, Oxford, pp 3594–3601
170. Yun-Feng C (2009) Study on the response of Lake Chaohu eutrophication to Yangtze River – Lake Chaohu Water Transfer Project. In: World Congress on Computer Science and Information Engineering, pp 614–619
171. Zhang S, Li C, Huang S, Zheng J (2008) Trophic states and nutrient storage of reservoirs in Chongqing. Chin J Geochem 27:310–316
172. MWRI (2005) Water for the Future, National Water Resources Plan for Egypt – 2017
173. Springuel I, Ali O (2005) The River Nile Basin. In: Fraser LH, Keddy PA (eds) The world's largest wetlands: ecology and conservation. Cambridge University Press, Cambridge
174. Abdel Latif AF (1984) Lake Nasser. In: Kapetsky JM, Petr T (eds) Status of African reservoir fisheries, vol 10. CIFA Technical Paper – CIFA/CPCA/T10 FAO CIFA Technical Paper
175. Abdel Latif AF (1984) Lake Nasser – the new man-made lake in Egypt (with reference to Lake Nubia). In: Taub FB (ed) Lakes and reservoirs, vol 23, Ecosystems of the world. Elsevier Science Publishers B.V., Amsterdam
176. El Shahat MM (2000) Lake Nasser overview. In: Craig JF (ed) Sustainable fish production in Lake Nasser: ecological basis and management policy. International Center for Living Aquatic Resources Managemen (ICLARM), Penang, Malaysia
177. Rashid MM (1995) Some additional information on limnology and fisheries of Lakes Nasser (Egypt) and Nubia (Sudan). In: Crul RCM, Roest FC (eds) Current status of fisheries and fish stocks of the four largest African reservoirs: Kainji, Kariba, Nasser/Nubia and Volta, vol 30. CIFA Technical Paper – CIFA/CPCA/T30 FAO CIFA Technical Paper
178. Said R (1993) The river Nile: geology, hydrology, and utilization. Pergamon, Oxford
179. Whittington D, Guariso G (1983) Water management models in practice: a case study of the Aswan High Dam. Elsevier Scientific, Amsterdam
180. Saad MBA (2000) Conflicts between users. In: Craig JF (ed) Sustainable fish production in Lake Nasser: ecological basis and management policy. International Center for Living Aquatic Resources Managemen (ICLARM), Penang, Malaysia
181. MWRI (2002) Adopted measures to face major challenges in the Egyptian Water Sector
182. Williams WD (2005) Lakes in arid environments. In: O'Sullivan PE, Reynolds CS (eds) The lakes handbook, vol 2: Lake restoration and rehabilitation. Blackwell Science Ltd
183. Habib OA (2000) Seasonal variation of phytoplankton abundance. In: Craig JF (ed) Sustainable fish production in Lake Nasser: ecological basis and management policy. International Center for Living Aquatic Resources Managemen (ICLARM), Penang, Malaysia
184. Craig JF (ed) (2000) Sustainable fish production in Lake Nasser: ecological basis and management policy. International Center for Living Aquatic Resources Managemen (ICLARM), Penang, Malaysia

185. El Moattassem M, Rafik M, Makary A, Heikal MT, Ramadan A (1993) Review of Aswan High Dam Lake water quality. In: ICOLD (ed) International symposium on High Aswan Dam: vital achievements, fully controlled Cairo, Egypt, 1993. Egyptian National Committee on Large Dams (ENCOLD)
186. El-Shabrawy GM (2009) Lake Nasser–Nubia. In: Dumont HJ (ed) The Nile: origin, environments, limnology and human use. Springer, Heidelberg, p 818
187. Clescerl LS, Greenberg AE, Eaton AD (eds) (1999) Standard methods for the examination of water and wastewater, 20th edn. American Public Health Association: American Water Works Association: Water Environment Federation
188. Abdelbary MR, EI Sherbini A, Heikal MT (1997) Water quality conditions in Lake Nasser with emphasis of eutrophic and stratification phenomena. Paper presented at the 9th World Water Congress of IWRA. Water resources outlook for the 21st century: conflicts and opportunities, Montreal, Canada
189. Abdelbary MR, EI-Moattassem M, Heikal MT (1997) Lake Nasser and Nile water quality as compared to bottled drinking water. Paper presented at the 5th Nile 2002 conference, Addis Ababa, Ethiopia
190. Heikal MT, Abdelbary MR (1999) Stratification variability and trophic state along Lake Nasser. Paper presented at the 8th International Conference on the Conservation and Management of Lakes Copenhagen, Denmark
191. Heikal MT, Abdel-Bary MR, EI-Sherbini AH (1998) Trophic status of Lake Nasser. Paper presented at the International Conference on Coping with Water Scarcity Hurghada, Egypt
192. El-Otify AM (2015) Evaluation of the physicochemical and chlorophyll-a conditions of a subtropical aquaculture in Lake Nasser area, Egypt. Beni-Suef Univ J Basic Appl Sci 4:327–337. doi:10.1016/j.bjbas.2015.11.009
193. Goher ME, Farhat HI, Abdo MH, Salem SG (2014) Metal pollution assessment in the surface sediment of Lake Nasser, Egypt. Egyptian J Aquat Res 40:213–224. doi:10.1016/j.arabjc.2012.06.001
194. Khalifa N, El-damhogy KA, Fishar MR, Nasef AM, Hegab MH (2015) Using zooplankton in some environmental biotic indices to assess water quality of Lake Nasser, Egypt. Int J Fisheries Aquat Stud 2:281–289
195. Awadallah RM, Soltan M (1995) Environmental, physical, and chemical changes of Lake Nubia-Aswan High Dam Lake water. J Environ Sci Health A Environ Sci Eng 30 (9):2071–2087
196. Abou El Kheir WS, Ibrahim EA, Khalil MM, Heikal MT, Yousry KM (2003) Assessment of physico-chemical characteristics of water and phytoplankton growth in Lake Nasser. J Environ Sci 7(1)
197. Hussein WO, Shafi EAE (2005) Environmental study on water quality assessment and prediction in Lake Nasser by using monitoring networks. In: Ninth International Water Technology Conference, Sharm El-Sheikh, Egypt, pp 1265–1280
198. Gharib SM, Abdel-Halim AM (2006) Spatial variation of phytoplankton and some physico-chemical variables during the highest flood season in Lake Nasser (Egypt). Egyptian J Aquat Res 32(1):246–263
199. Heikal MT (2010) Impact of water level fluctuation on water quality and trophic state of Lake Nasser and its Khors, Egypt. Egyptian J Aquat Biol Fisheries 14(1):75–86
200. Carlson RE, Simpson J (1996) A coordinator's guide to volunteer lake monitoring methods. North American Lake Management Society
201. TLUG (2004) Gewässergütekarte "Stehende Gewässer" Stand 2003 – Begleitheft -. Ministerium für Landwirtschaft, Naturschutz und Umwelt, Thüringer Landesanstalt für Umwelt und Geologie

Part II
The Nile from Aswan to its Promontories

Morphological Variation of the Nile River First and Second Reaches Using RS/GIS Techniques

Abdelazim Negm, Mohamed Elsahabi, Reham El-Sayed, Neama Abd El-Basset, Shenouda Ghaly, and Kamal Ali

Abstract The Nile River morphology has changed in the last century, due to the geological, topographical and climatological conditions, as well as due to the human impacts. The main focus of the present study is to detect the surface morphological changes in the first and second Nile River reaches (south of Egypt). For this purpose, several Landsat images acquired at different dates are utilized and analysed based on Remote Sensing (RS) and GIS techniques. Different satellite-derived indices including Normalized Difference Water Index (NDWI), Water Ratio Index (WRI) and Automated Water Extraction Index (AWEI) are applied to generate the (land-water) maps from Landsat data and to create the maps of changes in order to detect the changes in the water surface areas. The results indicated high performance of NDWI in generating the (land-water) maps and creating the maps of changes in both studied reaches of Nile River. For the first reach, NDWI has the highest overall accuracy (about 99.23%) and the lowest absolute error when applied for surface change detection. For the second reach, the NDWI index gave an overall accuracy of 99.13% which indicate the effectiveness and superiority of this index in detecting the surface morphological changes. Moreover, the results for the first reach of the Nile River showed a slightly change in the water surface area during the period 1984–2011. The Nile River in the considered reach lost about 2.3% of its surface area. Meanwhile, the results for the second reach indicated an intense decreasing in the water surface area in the period 1984–2010 (about 13% of the water area in the year 1984), and the utmost of this decreasing occurred over the period from the year 2005 to the year 2010 (about 8.3%).

A. Negm (✉)
Water and Water Engineering Department, Faculty of Engineering, Zagazig University, Zagazig 44519, Egypt
e-mail: amnegm85@yahoo.com; amnegm@zu.edu.eg

M. Elsahabi, R. El-Sayed, N.A. El-Basset, S. Ghaly, and K. Ali
Civil Engineering Department, Faculty of Engineering, Aswan University, Aswan, Egypt
e-mail: staff.civil.eng@aswu.edu.eg

A.M. Negm (ed.), *The Nile River*,
Hdb Env Chem (2017) 56: 147–170, DOI 10.1007/698_2016_126,

Keywords First reach, GIS, Morphological changes, Nile River, Remote sensing, Second reach

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1 Introduction

Water resources are crucial for sustaining human life and our environmental activities [1]. Those resources also are considered the most significant water cycle component [2], particularly, fresh water of rivers. Rivers have been the core of formation and maturation of human civilization since many centuries ago. So those, the shore of rivers are considered as appropriate places for agricultural, industrial and commercial activities.

The term river morphology is used to describe the shapes of river channels and how it changes in shape and direction over time [3]. Also, morphology (of river) is a field of science which deals with the change of river plan form.

The morphology of river is a function of a number of processes and environmental condition, including the composition and edibility of the bed and the banks (e.g. sand, clay, bedrock); erosion comes from the power and consistency of the current, and can affect the formation of the river's path. Also, the availability of sediment; the size and the composition of sediment moving through the channel; the rate of sediment transport through the channel and the rate of deposition on the floodplain, banks and bed. River morphology can also be affected by human interaction. Accordingly, the studies of morphological changes play an important role in sustainable river management and restoration structures as well as for mitigating flood risk [3].

River morphology has been a subject of great challenge to scientists and engineers who recognize that any effort with regard to river engineering must be based on a proper understanding of the morphological changes [4].

On the other hand, the Nile River is the longest river in the world with 6670 km long and 3.20 million km^2 catchment area. The Nile is very vital to Egypt as it is considered the main source of fresh water for most of its populations. This river has experienced major morphological changes during the past decades. The changes of flow discharges (for both cases; high and low flows), suspended sediment concentration changes, human interventions and the effect of new projects have major contribution for these changes [5].

In the recent decades, monitoring the surface morphological changes of rivers, especially that occurred due to sediment and erosion, has been easily done using the huge data introduced by remote sensing systems and analysed by using GIS techniques [6].

Although many studies related with detecting the morphological changes in water bodies have been carried out on rivers and lakes all over the world (e.g. Rokni [7], El-Asmar [8], Ma [9], Cruzio [10], El Gammal [11], Du [12], Alam [13], Mohammadi [14] and Moghaddas [15]), the literature contains very few floristic records for the Nile River (Mostafa [5] and Raslan [16]). References [7–11] deal with detecting the morphological changes in lakes, while those from [12–16] deal with rivers morphological changes.

The main purpose of this study is to detect the morphological changes (particularly in the water surface area) of the first reach of Nile River from Aswan City to Esna barrages and the second reach from Esna barrages to Nagaa Hammady barrages using RS data and GIS. The outcomes of this study will contribute to enhance the existing knowledge on the Nile River morphology and will help those who are responsible for sustainable development, management and protection of the Nile. Moreover, the study outcomes open the doors for future research for improvement and sustaining of the navigation paths/requirements through the Nile.

2 Description of the Study Areas

The Nile River serves crucial functions to the population of this country. This River is divided into four reaches. The first reach starts from Aswan city downstream (DS) of Aswan High Dam (AHD) to the upstream (US) of Esna barrages. The second reach begins from the DS of Esna barrages to the US of Nagaa Hammady barrages. The third reach links between the DS of Naga Hammady barrages to the US of Assiut barrages. Eventually, the fourth reach is considered from the DS of Assiut barrages to the US of Delta barrages. The first and second reaches are

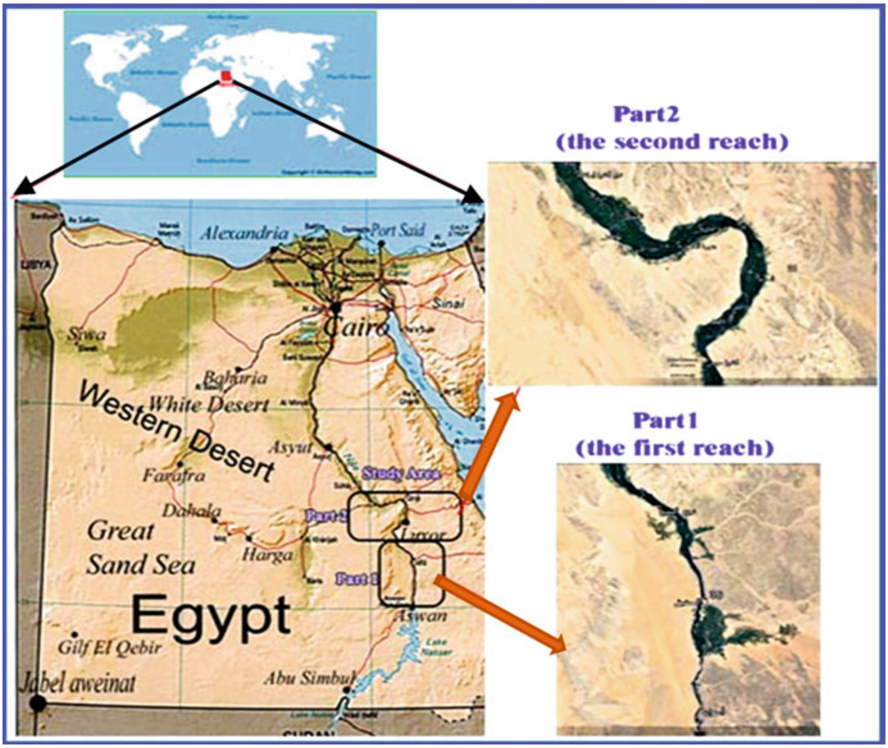

Fig. 1 Location of the study areas (the first and second reaches) in Nile River

selected to be the study areas of the present chapter (see Fig. 1). These reaches have been selected for this study because: (1) data about the morphology changes in these reaches are limited, even though these data are considered the major data for improvement and sustaining of the navigation paths/requirements through the Nile (2) satellite data have not been used yet to derive the surface morphological changes of the first and second reaches of Nile River; (3) they are located in a navigable river (Nile); and (4) satellite imageries data, as well as an old digital maps (for validation), were available for both reaches.

2.1 The Reach from Aswan City to Esna Barrages

The first part of the study area covers the first reach that extends between latitudes 23° 58′ 17.56″ N and 25° 19′ 3.3″ N (DS of AHD).

2.2 The Reach from Esna Barrages to Nagaa Hammady Barrages

The second part of the study area represents the second reach that extends between latitudes 25° 19′ 00″ N and 26° 09′ 10″ N (DS of AHD).

3 Collected Data

3.1 Satellite Data

Landsat TM/ETM+ imagery data were used to enable the monitoring and detection of surface morphological changes of the study reaches. TM/ETM+ imagery data were chosen because of their long-term data availability (since 1984), free access and high spatial resolution (30 m) [17]. One scene of a Landsat image can entirely cover the second reach with (Path/Row = 174/042), while two scenes are needed to completely cover the first reach of the Nile with (Path/Row = 174/043, 175/042). The images have been acquired in the years 1984, 1999, 2005 and 2011 for the first reach, meanwhile they have been acquired in the years 1984, 1999, 2005 and 2010 for the second reach. The acquisition dates of images for the two reaches are given in Table 1. The data were downloaded freely from the United States Geological Survey (USGS) earth explorer website [18] in Geotiff (systematic correction) product. Consequently, they are free of geometric, radiometric and noise errors. These images data were geo-referenced by USGS using the world reference system (WGS-84 datum) to Universal Transverse Mercator (UTM) system zone, 36 North projection. All imageries were obtained for the same season almost (summer) to avoid the seasonal water level changes.

The thematic mapper (TM) and the enhanced thematic mapper (ETM+) imageries contain seven bands in blue, green, red, near infrared (NIR), mid infrared (MIR) and shortwave infrared (SWIR) = band7 with spatial resolution of 30 m, expect for the thermal band = band6, where it has a spatial resolution of 120 m for TM imageries and 60 m for ETM+ imagery [19].

Table 1 The specifications of Landsat TM and ETM+ images

Satellite	Sensor	Path/Row	Year	Spatial resolution (m)
Landsat-5	TM	174/043 175/042	1984	30
Landsat-7	ETM+	174/043 175/042	1999 2005 2010 2011	30

3.2 Digital Maps

Old digital maps for both study sites, with scale 1:5000 (compiled from aerial photography in 1999), are used to check the validation of remotely sensed extracted data from the Landsat images.

4 Methodology

Figure 2 presents the main tasks/activities conducted to achieve the objective of the present study. The next few sections present an explanation for detailed methodologies.

4.1 Pre-processing of Landsat Satellite Images

The first reach is covered by two satellite images in each year from 1984 to 2011 with two different paths/rows. So, firstly it was required to mosaic the two images with path/row of 174/043 and 175/042 for each studied year. In this step, the two images were merged together to generate a new image covering the entire study area. The second step is clipping the images to cover only both of the study reaches, since the collected Landsat images cover areas bigger than the study reaches. The pre-processing step is performed using data management tools (mosaic and clip tools) in ArcGIS 9.3 software [20].

4.2 Generating of (Land-Water) Maps

Three spectral water indices, NDWI, AWEI and WRI, are applied to find out which index is the best indicator of generating (land-water) map for year 1984. These indices are calculated by using raster calculator of ArcGIS 9.3 software. All the indices equations which relay on the variations in the satellite images bands are illustrated in Table 2.

In Normalized Difference Water Index (NDWI) equation, water features have positive values, while land area usually has zero or negative values [7]. In case of Water Ratio Index (WRI), water features have values greater than 1 [21]. Furthermore, water features have positive values in case of Automated Water Extraction Index (AWEI) [22]. After the generation process of (land-water) maps, the filtering process is applied to the generated maps in order to reduce the errors in the generation process and to increase the accuracy of the derived maps. This process is based on omission of the small misclassified areas.

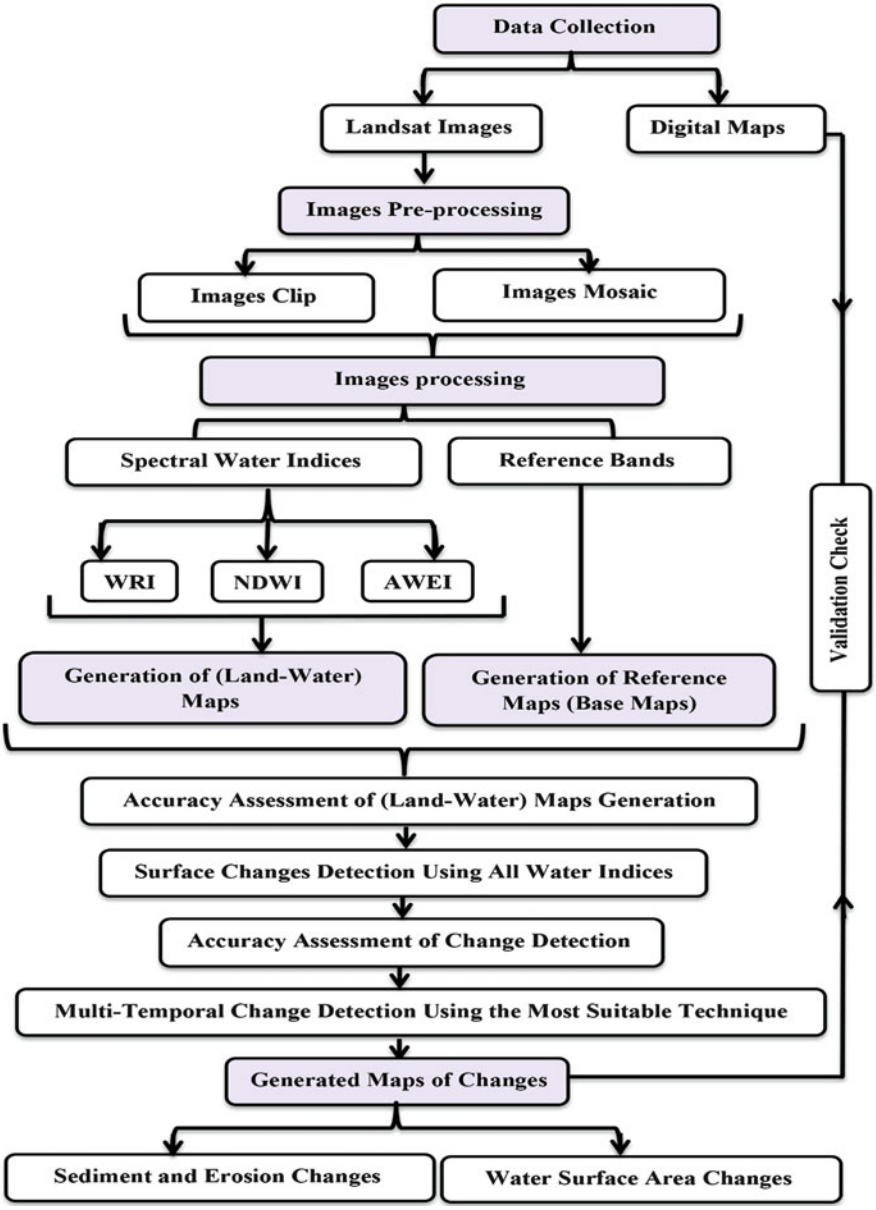

Fig. 2 Methodological flowchart of the present study

Table 2 Different spectral water indices for generating (land-water) maps

Equation no.	Index	Equation statement
1	Normalized Difference Water Index [7]	$NDWI = \frac{Green - NIR}{Green + NIR}$
2	Water Ratio Index [21]	$WRI = \frac{Green + Red}{NIR + MIR}$
3	Automated Water Extraction Index [22]	$AWEI = 4 * (Green - MIR) - (0.25 * NIR + 2.75 * SWIR)$

4.3 Reference Maps

In this study we select the near-infrared (NIR) band to generate the reference map (base map), due to its higher ability to discriminate water from land areas. As this band is strongly absorbed by water and is strongly reflected by the terrestrial vegetation and dry soil [22], the reference maps were generated from the NIR band using on-screen digitizing.

4.4 Accuracy Assessment of (Land-Water) Maps Generation

The overall accuracy and absolute error were computed by overlaying the created reference maps with the (land-water) maps which generated from spectral water indices to evaluate the performance of each index and to assess the validation of these indices for generating the (land-water) maps.

4.5 Surface Changes Detection Using All Water Indices

In this respect, change maps of the first reach were generated by comparing and overlaying (land-water) map of year 1984 with (land-water) map year 2011 for each index. For the second reach, the generation of the change maps was achieved by comparing and overlaying (land-water) map of year 1984 with (land-water) map year 2010 for each index. In these periods, the changes in the surface area are likely clear and observed to help in the accuracy assessment of the change detection technique for both studied reaches.

4.6 Accuracy Assessment of Change Detection

In order to evaluate the effectiveness of the proposed approach for surface morphological change detection, different accuracy assessment analyses are performed.

In this respect, the absolute error and the overall accuracy of the derived changes between years 1984 and 2011 for the first reach and between years 1984 and 2010 for the second reach are calculated for each index based on the derived changes maps and the reference changes results.

4.7 Multi-Temporal Change Detection Using the Most Suitable Technique

To perform this task, the most suitable technique that has the highest overall accuracy was applied for extracting and detecting the surface morphological changes during periods (1984–1999), (1999–2005) and (2005–2011), respectively, for the first reach and from (1984–1999), (1999–2005) and (2005–2010), respectively, for the second reach. Finally, the validation check of the created changes maps was carried out using check samples from the 1999 using old digital maps (at scale of 1:5000).

5 Results

Section 5.1 presents the results for the first reach while Sect. 5.2 presents the results for the second reach.

5.1 Results for the First Reach

5.1.1 Generation of (Land-Water) Maps

The derived (land-water) maps were generated from the applied three water indices and from reference Landsat bands for both the year 1984 and the year 2011 only. These maps were derived after performing the filtering process, which was performed for elimination and omission of the misclassified pixels. The generated (land-water) maps of year 1984 are shown in Fig. 3 as sample results.

5.1.2 Surface Change Detection

Figure 4 shows the generated change maps over the period from 1984 to 2011 by overlaying the derived (land-water) maps of the year 1984 with that of the year 2011. Besawi Island which is located between latitude 24° 41′ 42″ N and 24° 42′ 45″ N was chosen as a typical island to present its results (see Fig. 4). The surface

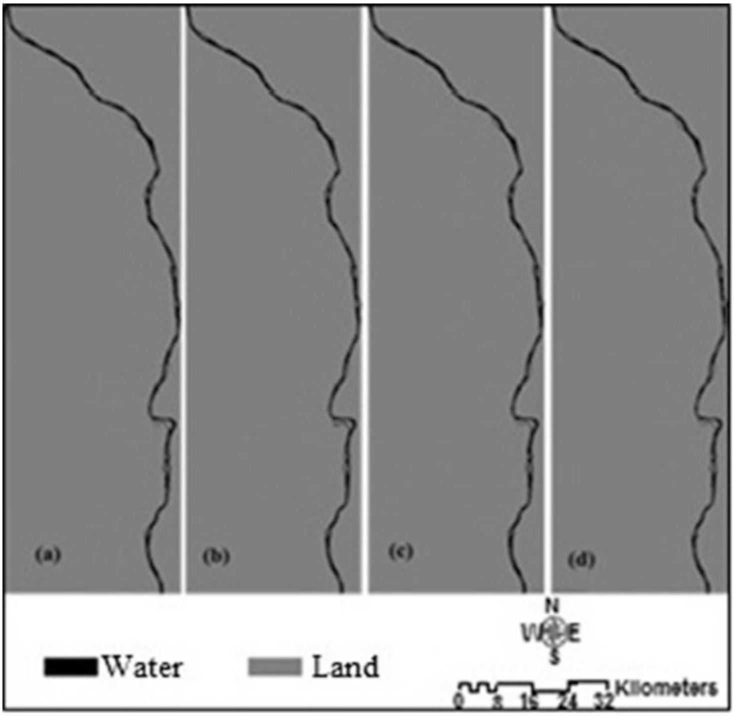

Fig. 3 The resulting (land-water) maps from Landsat image 1984: (**a**) reference map, (**b**) NDWI Map, (**c**) WRI map and (**d**) AWEI map

morphological change of this island was considered the maximal change through the study reach from Aswan to Esna for the period from the year 1984 to the year 2011.

5.1.3 Generation of (Land-Water) Maps Using NDWI Index Only

The generated (land-water) maps for the years 1984, 1999, 2005 and 2011 using NDWI which is considered the most suitable water index for change detection are shown in Fig. 5.

5.1.4 Multi-Temporal Change Detection Using the Most Suitable Technique

The generated NDWI (land-water) maps for years 1984, 1999, 2005 and 2011 were overlaid using ArcGIS software to produce the multi-temporal change maps. The change maps of Besawi Island are illustrated in Fig. 6 as typical sample results.

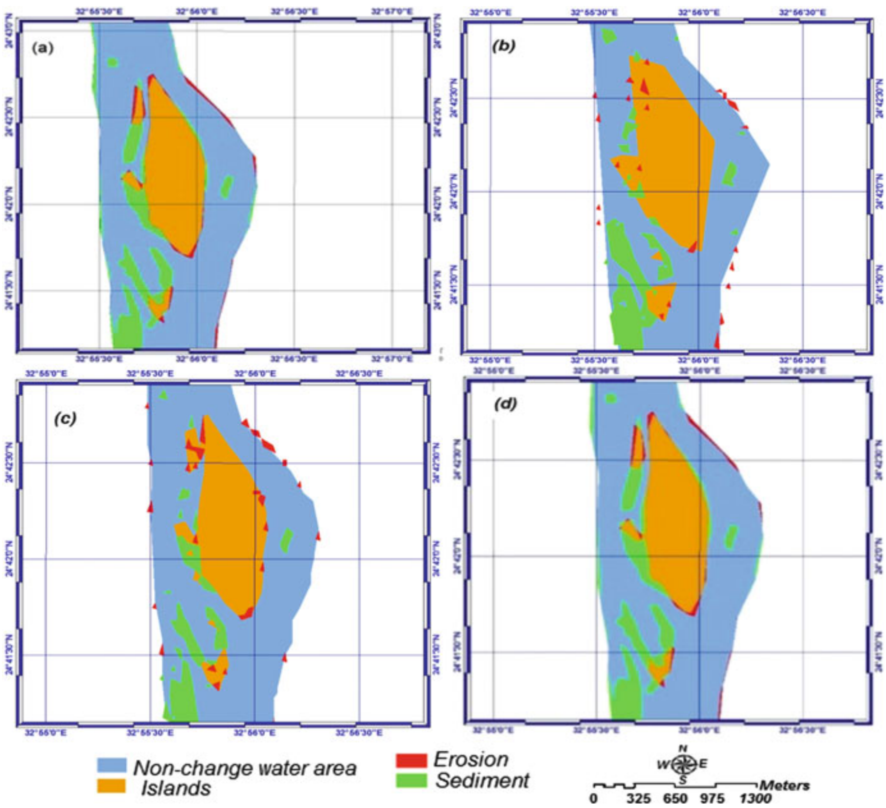

Fig. 4 The change detection maps from the year 1984 to the year 2011: (**a**) reference change map, (**b**) AWEI change map, (**c**) WRI change map and (**d**) NDWI change map for island Besawi and its fringes [23]

5.2 Results for the Second Reach

5.2.1 Generation of (Land-Water) Maps

Generation of (land-water) maps by all water indices and from reference bands was applied for the years 1984 and 2010 only. Then these maps were exposed to filtering process. Figure 7 shows the derived (land-water) maps from satellite-derived indexes for year 1984 as sample results.

5.2.2 Surface Change Detection

Figure 8 shows the results of the change maps in the period from the year 1984 to the year 2010 using NDWI, AWEI and WRI. The results at AL Samata Island which extends between latitude 26° 06′ 43″ N and 26° 06′ 57″ N were selected as

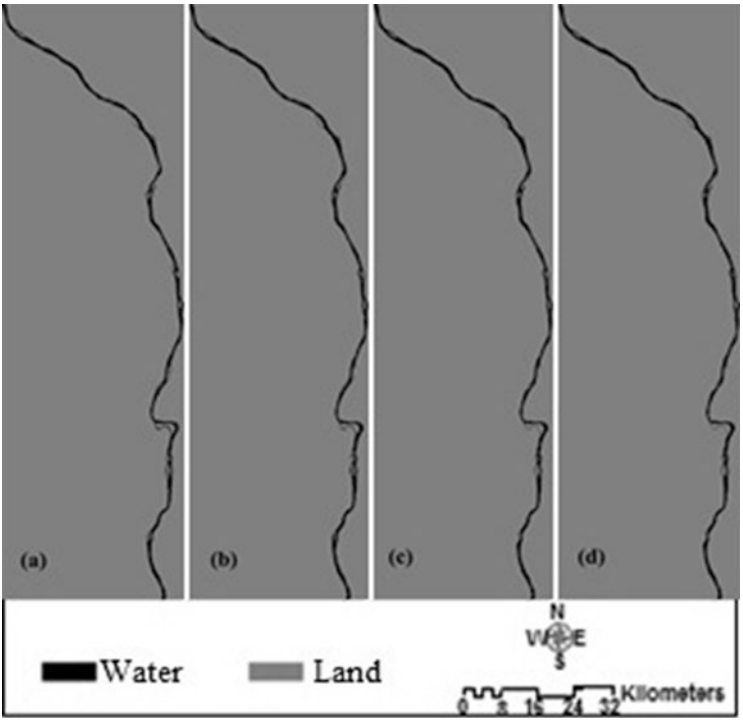

Fig. 5 The NDWI (land-water) maps: (**a**) map of 1984, (**b**) map of 1999, (**c**) map of 2005 and (**d**) map of 2011

sample results from all detected islands in the study area. AL Samata island is exposed to various changes in the study period and it has the maximal area of changes through the study area.

5.2.3 Generation of (Land-Water) Maps Using NDWI Index Only

The generated (land-water) maps for the years 1984, 1999, 2005 and 2010 using the most suitable technique for change detection (NDWI) are shown in Fig. 9.

5.2.4 Multi-Temporal Change Detection Using the Most Suitable Technique

The change maps between years 1984, 1999, 2005 and 2010 were produced from the generated NDWI maps of these years using ArcGIS software. The change maps of AL Samata Island are illustrated in Fig. 10 as sample results.

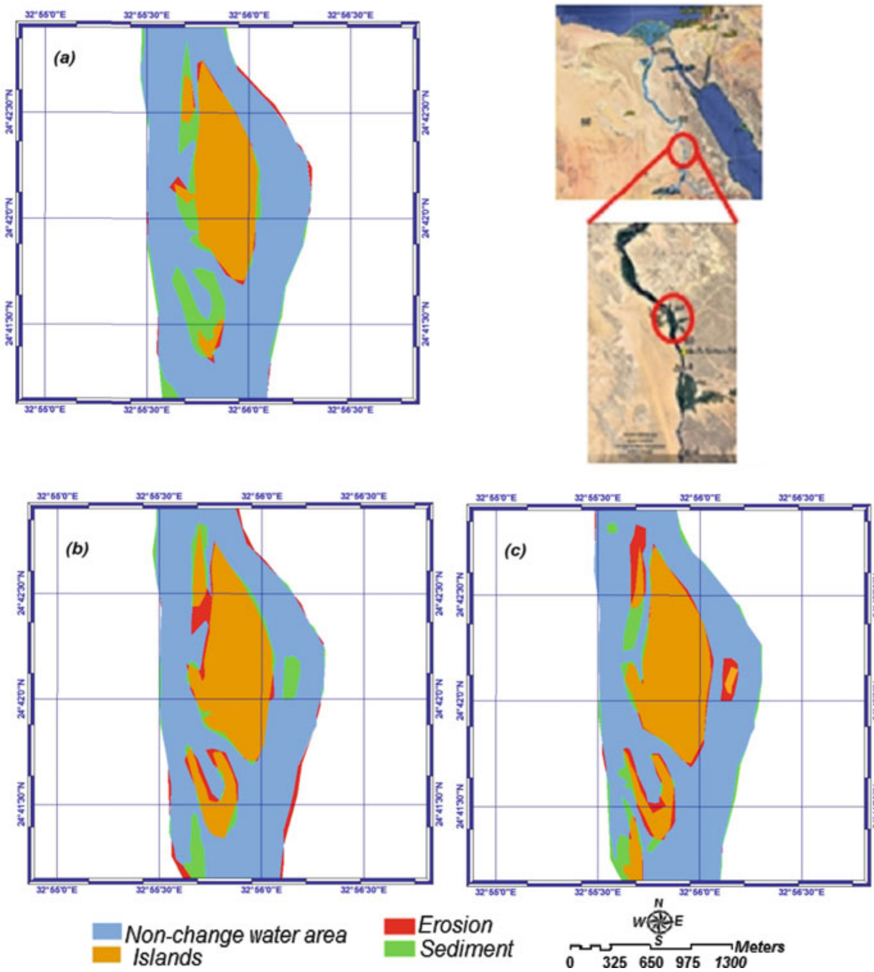

Fig. 6 The multi-temporal change maps: (**a**) 1984–1999, (**b**) 1999–2005 and (**c**) 2005–2011 for island Besawi and its fringes [23]

6 Discussions

Section 6.1 presents the discussions for the first reach while Sect. 6.2 presents the discussions for the second reach.

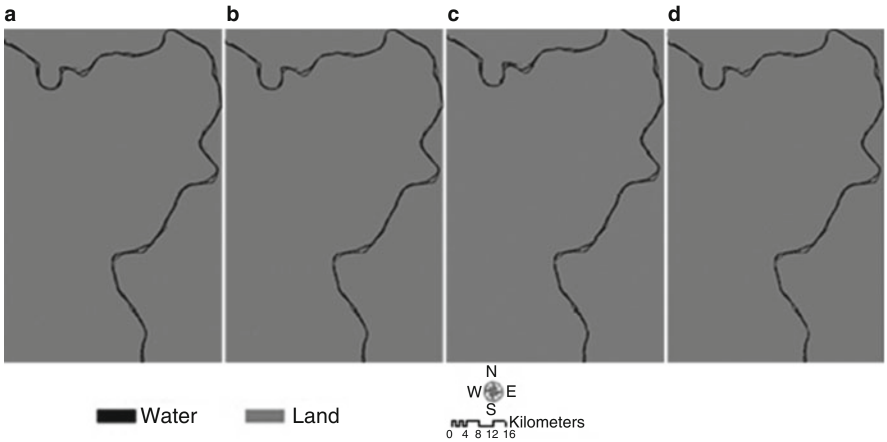

Fig. 7 The derived (land-water) maps from Landsat TM image (1984): (**a**) reference map, (**b**) NDWI map, (**c**) WRI map and (**d**) AWEI map

6.1 Discussions for the First Reach

6.1.1 Accuracy of (Land-Water) Maps Generation

Table 3 illustrates the accuracy assessment analysis of the generated (land-water) maps of the year 1984 that are shown in Fig. 3. A comparison between the water surface area in the created (land-water) maps of the year 1984 (created from spectral water indices) with reference water area in the generated reference map for the same year is conducted. The results show superiority and higher performance of the NDWI method for generating (land-water) maps compared to other methods. The NDWI achieved an absolute error of 0.97 km^2 and an overall accuracy of 99.05% (the highest accuracy).

6.1.2 Surface Change Detection

The computed absolute error and overall accuracy for assessing the accuracy of the generated change maps in the period 1984–2011 using NDWI, AWEI and WRI (see Fig. 4) are illustrated in Table 4. Accuracy assessment analysis according to this table indicates the superiority of the NDWI method for surface water change detection compared with other methods. The NDWI achieved an absolute error of 0.08 km^2 and an overall accuracy of 99.23%.

Accordingly, the NDWI was used to model the multi-temporal changes of the study area in the period 1984–2011 (see Fig. 6). For this purpose, the NDWI was calculated from Landsat images of the years 1984, 1999, 2005 and 2011 to generate the (land-water) maps of these years as shown previously in Fig. 5. The water areas

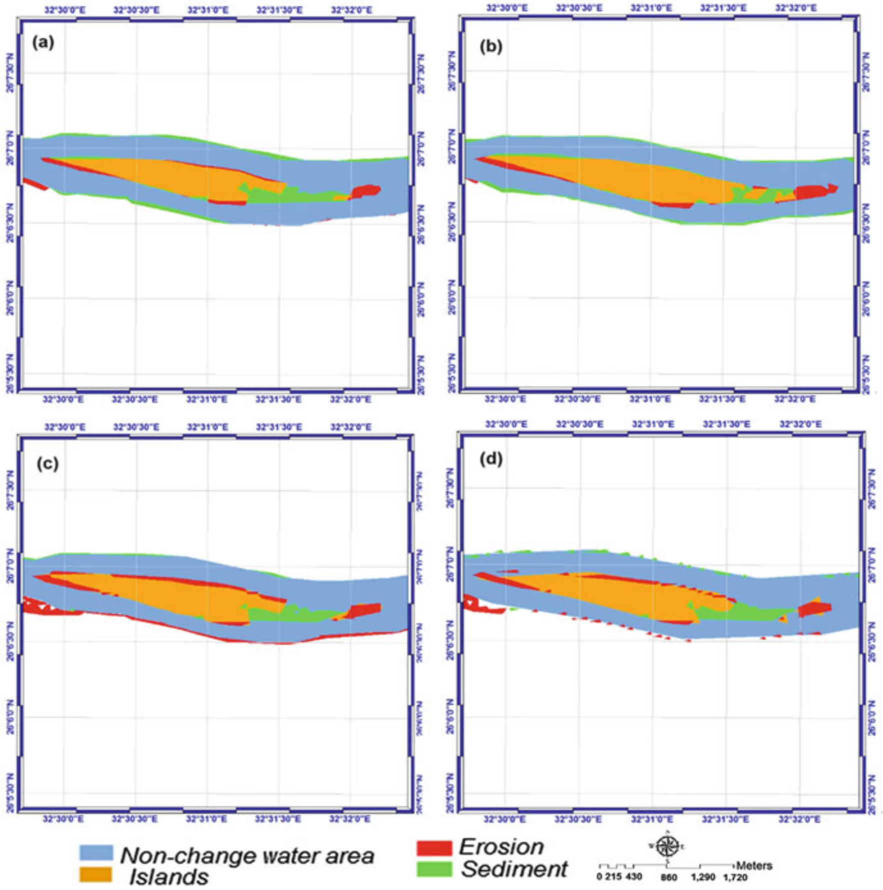

Fig. 8 The change detection maps from the year 1984 to the year 2010: (**a**) reference change map, (**b**) NDWI change map, (**c**) AWEI change map and (**d**) WRI change map for island AL Samata and its fringes [24]

were computed from these maps using ArcGIS software and its values were illustrated in Fig. 11 and Table 5.

According to Fig. 11, it is obvious that from the year 1984 to the year 1999 and from the year 2005 to the year 2011 no significant change has been observed. While, a bit significant change has occurred in the water surface of the study area during the period from the year 1999 to the year 2005. Overall the results showed that the total surface area changes of the first reach between year 1984 and year 2011 were decreased by about 2.39 km^2. The decrease in the water surface area of the first reach in this period may be attributed to the changes in the surface areas of sediment and erosion for both the Nile River banks and islands in the same period. A morphodynamic investigation is needed to understand the mechanism of such changes (sediment and erosion processes). Overall, the loss in the water surface area can be explained through a future morphodynamic study.

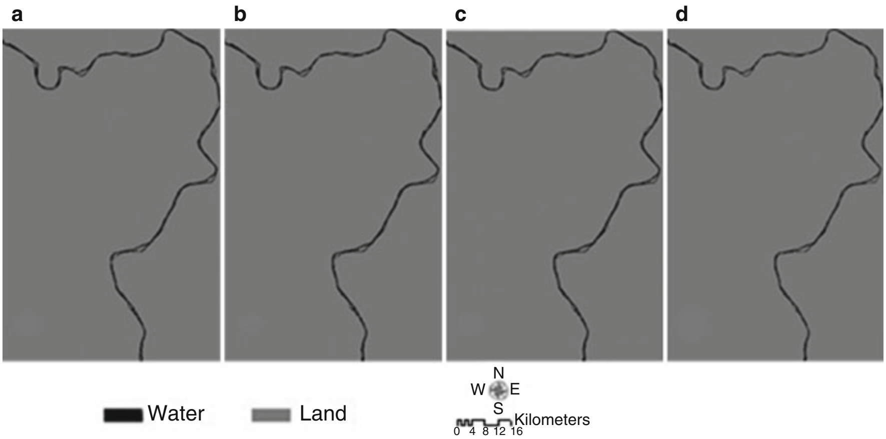

Fig. 9 The NDWI (land-water) maps: (**a**) map of 1984, (**b**) map of 1999, (**c**) map of 2005 and (**d**) map of 2010

According to Fig. 6 it is observed that the maximal changes are observed around the middle parts of the reach particularly, around the islands.

Table 5 shows statistics of the multi-temporal changes in water surface area of the first reach. It is obvious from this table that the studied river reach lost about 2.3% of its surface area in the period 1984–2011.

Figures 12 and 13 show the change in sediment and erosion surface areas, respectively, from the year 1984 to the year 2011, that were estimated by using the statistics of the change categories (classes) in the multi-temporal change maps. It is obvious from these figures that there is an increase in the surface area of sediment accompanied with decrease in the surface areas of erosion compared with that of sediment in the periods from 1984 to 1999 and from 1999 to 2005. While, there is a slight decrease in the surface area of sediment from year 2005 to year 2011 compared with the area of erosion in the same period.

6.2 Discussions for the Second Reach

6.2.1 Accuracy of (Land-Water) Maps Generation

The accuracy assessment of the 1984 generated (land-water) maps shown in Fig. 7 is analysed and illustrated in Table 6. This table shows high performance of the NDWI method for generating (land-water) maps compared with other methods with an absolute error of 1.22 km^2 and an overall accuracy of 98.62% for the computed surface water areas from these maps.

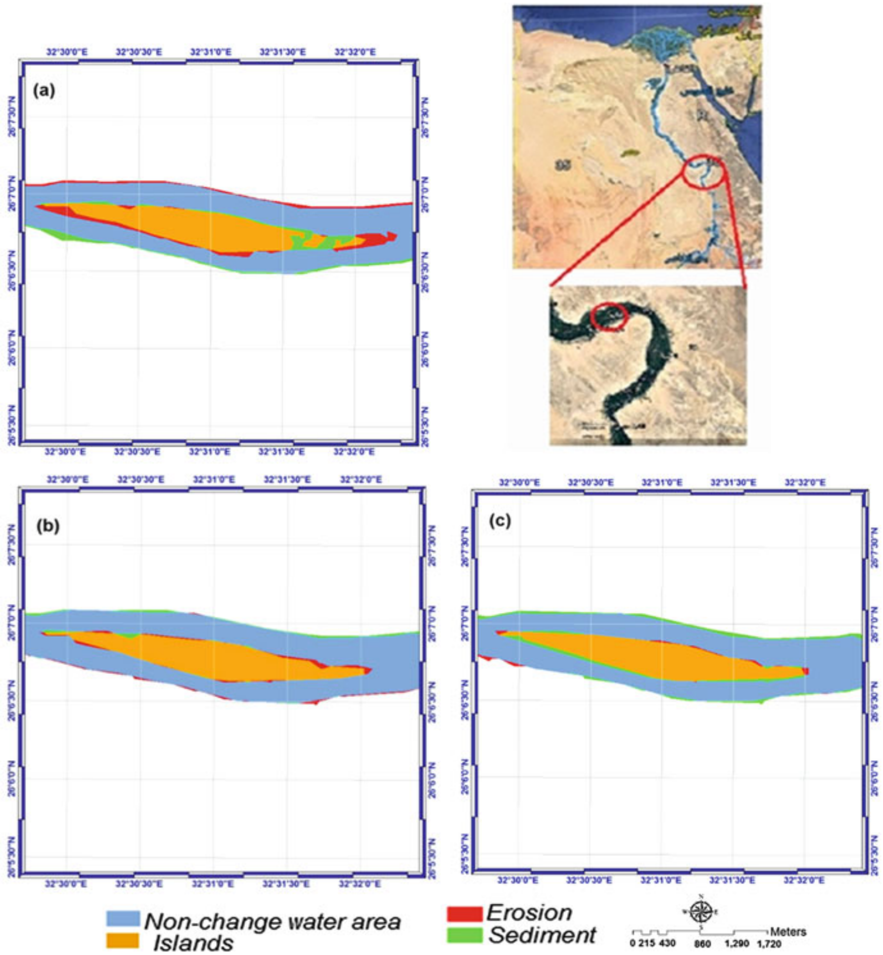

Fig. 10 The multi-temporal change maps: (**a**) 1984–1999, (**b**) 1999–2005 and (**c**) 2005–2010 for island AL Samata and its fringes [24]

Table 3 Accuracy assessment analysis of water surface extraction from (land-water) maps

Index	Water area in 1984 (km^2)	Absolute error (km^2)	Overall accuracy (%)
REF	101.95	–	100
NDWI	102.92	0.97	99.05
WRI	95.8	6.15	93.98
AWEI	98.45	3.50	96.82

Table 4 Accuracy assessment analysis of water surface area changes between the year 1984 and the year 2011

Index	Surface water area change (km^2)	Absolute error (km^2)	Overall accuracy (%)
REF	2.32	–	100
NDWI	2.40	0.08	99.23
WRI	0.34	1.98	80.94
AWEI	0.50	1.82	82.48

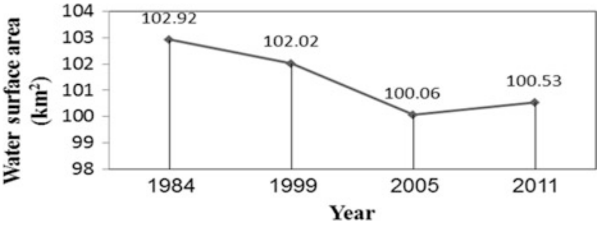

Fig. 11 The water surface areas in the period between 1984 and 2011 [23]

Table 5 Statistics of water surface area changes

Year	Surface area (km^2)	Surface area change (km^2)
1984	102.92	
		−0.90
1999	102.02	
		−1.96
2005	100.06	
		+0.47
2011	100.53	

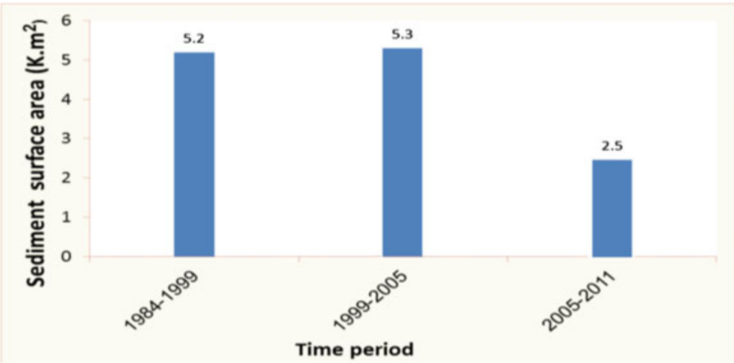

Fig. 12 Sediment surface area in the first reach

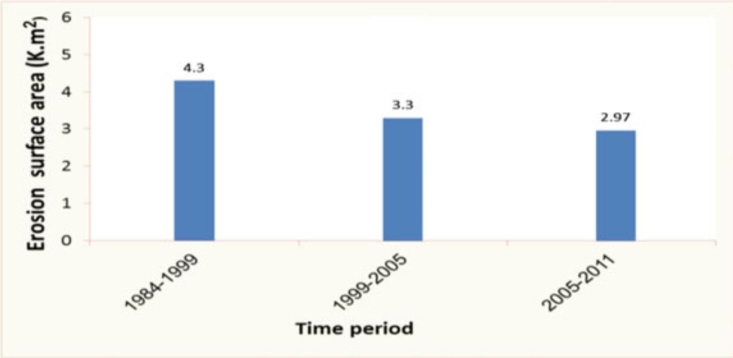

Fig. 13 Erosion surface area in the first reach

Table 6 Accuracy assessment analysis of water surface extraction from (land-water) maps

Index	Water area in 1984 (km^2)	Absolute error (km^2)	Overall accuracy (%)
Reference	101.65	0	100
NDWI	100.43	1.22	98.62
AWEI	92.99	8.66	90.20
WRI	99.23	2.42	97.26

6.2.2 Surface Change Detection

The accuracy of the derived change maps shown in Fig. 8 was assessed. The results were presented in Table 7. It is observed from this table that the NDWI method for surface morphological change detection (particularly, surface water area changes) provides the highest performance compared to other methods with an absolute error of 1.02 km^2 and an overall accuracy of 99.13%.

As the NDWI proved its high superiority in generating the change detection maps, it was used for generating (land-water) map for the years 1984, 1999, 2005 and 2010 individually (see Fig. 9) in order to detect the multi-temporal morphological changes that occurred in this study reach among these years (see Fig. 10). Figure 14 shows the computed water surface areas from the generated (land-water) maps through the second reach. According to Fig. 14 it is observed that there is no significant change in the water area in the periods (1984–1999) and (1999–2005). Meanwhile, there is a significant decrease in the water surface area by about 8.33 km^2 during the period from 2005 to 2010.

Table 8 shows the statistics of the multi-temporal changes in water surface area of the second reach. It is obvious from this table that the total decrease in the water area over the time period (1984–2010) was about 13.14 km^2 (about 13% of the total water area in year 1984).

Table 7 Accuracy assessment analysis of water surface area changes from the year 1984 to the year 2010

Index	Changed area (km^2)	Absolute error (km^2)	Overall accuracy (%)
Reference	−9.98	0	100
NDWI	−11	1.02	99.13
AWEI	+4.87	14.85	87.33
WRI	−1.44	8.54	92.72

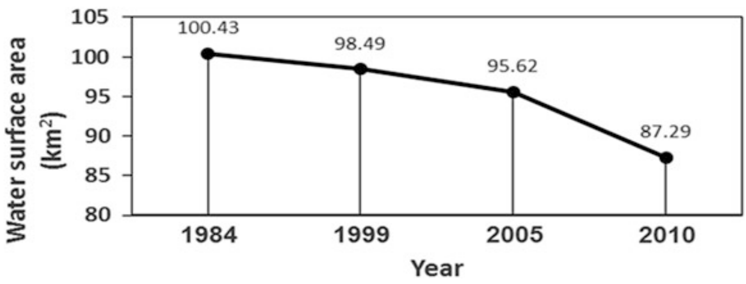

Fig. 14 The water surface areas in km^2 in the period between 1984 and 2010 [24]

Table 8 Statistics of water surface area changes

Year	Surface area (km^2)	Surface area change (km^2)
1984	100.43	
		−1.94
1999	98.49	
		−2.87
2005	95.62	
		−8.33
2010	87.29	

According to Fig. 10, it is recognized that most changes occurred in the river banks due to the accumulated sediment annually (sedimentation process) specially in the period from the year 2005 to the year 2010. This is considered the main cause for decreasing in the water surface area during this period. The sedimentation process in the river banks can be explained through a future morphodynamic study to understand the mechanism of the decreasing in the water surface area.

Figures 15 and 16 show the change in sediment and erosion surface areas, respectively, from the year 1984 to the year 2010, that were estimated by using the statistics of the change categories (classes) in the multi-temporal change maps. It is observed from these figures that there is an increase in the areas of sediment from the years 1984–1999, 1999–2005 and 2005–2010 accompanied with decrease in the surface areas of erosion compared with those of sediment in the same periods. Moreover, it is obvious that the highest increase in the surface area of sediment was

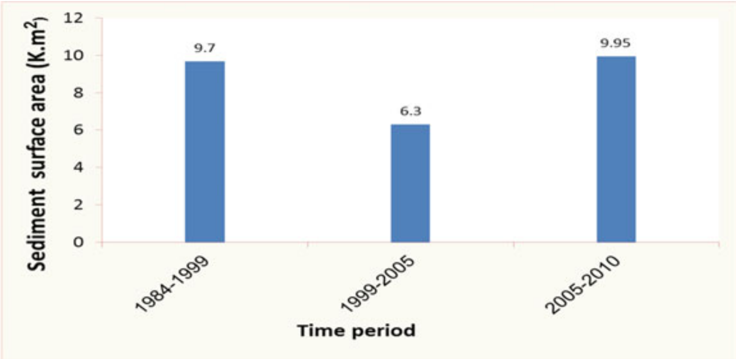

Fig. 15 Sediment surface area in the second reach

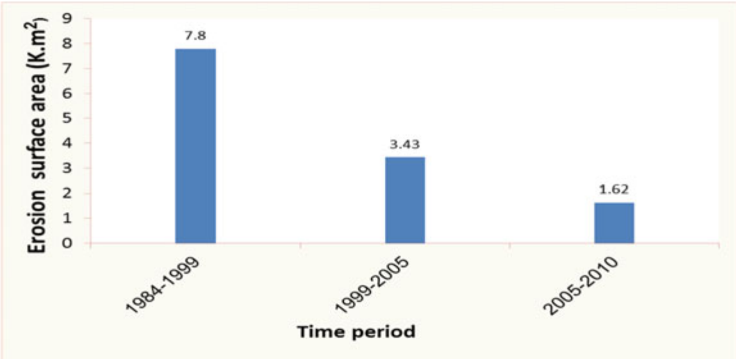

Fig. 16 Erosion surface area in the second reach

occurred from the year 1984 to the year 1999 which is nearly the same as the increase from 2005 to 2010. Meanwhile, the highest increase in the surface area of erosion was occurred from the year 1984 to the year 1999.

6.3 Validation Check of the Generated Maps of Changes

The validation check of the created multi-temporal change maps was carried out using 540 samples (about 270 samples for each reach). These samples were collected from the old digital maps (at scale of 1:5,000). Each every sample was created from more than one pixel. These samples were firstly selected at the change zones (sediment and erosion areas), and then crossed with the (1984–1999) map of changes shown in Fig. 6 for the first reach and Fig. 10 for the second reach. The calculated overall accuracy was (97.43%) for first reach and was (97.11%) for the second reach. Therefore, the generated maps of changes for the period from the year 1984 to the year 1999 for both reaches are acceptable. Consequently, the NDWI technique for generating the multi-temporal maps of changes in this study is considered an accurate and valid tool to be applied in the estimation of surface morphological changes of rivers.

7 Conclusions and Recommendations

This study presents and discusses the results of detecting the multi-temporal morphological changes in water surface areas of the first and the second reaches of the Nile River (inside Egypt) using RS/GIS technologies based on using Landsat images.

For the first reach, the results indicated that the superiority of the NDWI method for water change detection compared with other methods. The NDWI gave an overall accuracy of 99.23%. Moreover, the results showed that the total water surface area of the study river reach over the period between the year 1984 and the year 2011 is decreased by about 2.39 km^2 (2.3% of total area). It is observed in this reach that the maximal changes are located around the reach islands.

For the second reach, the results indicated that the NDWI method provided the highest performance (overall accuracy equal 99.13%) as compared with other techniques for the detection of water surface changes of the study river reach from Landsat data. On contrast, AWEI gave the lowest performance with an overall accuracy equal 87.33%. Interestingly, the results showed that the total decrease in the area of this studied river reach over the time period (1984–2010) was about 13.14 km^2 (about 13% of the total water area in year 1984). Moreover, the results illustrated that the maximum decrease of this studied reach water surface area occurred through the period (2005–2010) is about 8.33 km^2. It should be mentioned that the most changes in this reach occurred in the river banks due to the accumulated sediment annually (sedimentation process).

The authors recommend a future morphodynamic investigation to the same study area to understand the mechanism of the increase in the islands surface areas and to understand the mechanism of the sedimentation process through the river banks. Also, it is highly recommended to conduct the same study on other reaches of the Nile River as pre-investigations for future studies on the improvement and sustaining of the navigation paths/requirements through the Nile.

References

1. Ridd MK, Liu JA (1998) Comparison of four algorithms for change detection in an urban environment. Remote Sens Environ 63:95–100
2. Ma M, Wang X, Veroustraete F, Dong L (2007) Change in area of Ebinur Lake during the 1998–2005 period. Int J Remote Sens 28:5523–5533
3. Rosgen D (1996) Applied river morphology. Wildland Hydrology, Fort Collins

4. Howard CH (2008) River morphology and river channel changes. Trans Tianjin Univ 14(4): 254–262. ©Tianjin University and Springer-Verlag 2008
5. Mostafa DA (2012) Morphological study of the Nile River fourth reach. Master of Science thesis, Irrigation and Hydraulics Department, Faculty of Engineering, Cairo University
6. Wilson EH, Sader SA (2002) Detection of forest harvest type using multiple dates of Landsat TM imagery. Remote Sens Environ 80:385–396
7. Rokni K, Ahmad A, Selamat A, Hazini S (2014) Water feature extraction and change detection using multitemporal Landsat imagery. J Remote Sens 6:4173–4189
8. El-Asmar HM, Hereher ME, El Kafrawy SB (2013) Surface area change detection of the Burullus Lagoon, North of the Nile Delta, Egypt, using water indices: a remote sensing approach. Egypt J Remote Sens Space Sci 16(1):119–123
9. Ma M, Wang X, Veroustraete F, Dong L (2007) Change in area of Ebinur Lake during the 1998–2005 period. Egypt J Remote Sens Space Sci 28(24):5523–5533
10. Curzio SL, Russo F, Caporaso M (2013) Application of remote sensing and GIS analysis to detect morphological changes in an artificial lake. Int J Remote Sens Geosci 2(4):2319–3484
11. El Gammal EA, Salem SM, El Gammal AA (2010) Change detection studies on the world's biggest artificial lake (Lake Nasser, Egypt). Egypt J Remote Sens Space Sci 13:89–99
12. Du Z, Linghu B, Ling F, Li W (2012) Estimating surface water area changes using time-seri Landsat data in the Qingjiang River Basin, China. J Appl Remote Sens 6:063609(1–16)
13. Alam JB, Uddin M, Ahmed JU, Yesmin N (2007) Study of morphological change of River Old Brahmaputra and its social impacts by remote sensing. Geographia Technica 2:1–11
14. Mohammadi A, Alaghmand S, Mosaedi A (2008) Study and determination of morphological changes of Dough River in North of Iran using GIS. Int Arch Photogramm Remote Sens Spat Inf Sci 3:1217–1220
15. Moghaddas NH, Jalilvand R, Soloki HR (2013) The investigation of the Sistan River morphology using Rosgen classification. Indian J Sci Technol 6(2). ISSN: 0974-6846
16. Raslan Y, Salama R (2015) Development of Nile River islands between Old Aswan Dam and new Esna barrages. Water Sci 29:77–92
17. Muala E, Mohamed Y, Duan Z, Zaag P (2014) Estimation of reservoir discharges from Lake Nasser and Roseires Reservoir in the Nile Basin using satellite altimetry and imagery data. Remote Sens (Basel) 6:7522–7545
18. United States Geological Survey (USGS). U.S. Department of the Interior U.S. Geological Survey (USGS Earth Explorer). http://earthexplorer.usgs.gov/
19. Landsat Technical Guide (2004) Institute for Advanced Computer Studies and Department of Geography, University of Maryland. http://www.glcf.umd.edu/library/guide/techguidelandsat.pdf
20. ESRI (2008) Environmental Systems Research Institute, Help topics of ArcGIS version 9.3 Desktop. Developer Center of Geographic Information Systems (GIS) Software, Redlands, California
21. Elsahabi M, Negm A, El Tahan MH (2016) Performances evaluation of surface water areas extraction techniques using Landsat ETM+ data: case study Aswan High Dam Lake (AHDL). Proc Technol 22:1205–1212
22. Elsahabi M, Negm AM, Ali K (2016) Performances evaluation of water body extraction techniques using Landsat ETM+ data: case-study of Lake Nubia, Sudan. Egypt Int J Eng Sci Technol 19(2):275–281
23. El-Sayed RM, Ghaly S, Ali KA, Negm AM (2016) Morphological variation of the Nile River Reach from Aswan City to Esna Barrage using RS/GIS. In: The 9th AICSGE, Alexandria, 19–21 Dec
24. Abd-El-Basset NG, Ghaly S, Ali KA, Negm AM (2016) Detecting morphological changes in the Nile River Islands: the reach from Esna Barrages to Nagaa Hamadi Barrages. In: The 9th AICSGE, Alexandria, 19–21 Dec

Bed Morphological Changes of the Nile River DS Major Barrages

Ahmed M. Abdel Sattar

Abstract Despite being the longest alluvial river in the world with longest path of sediment, the River Nile has received the least attention regarding the bed morphological changes especially downstream large man-made hydraulic structures such as barrages. Flow sediment interaction is expected to cause a wide range of bed geomorphologic changes in the River Nile affecting river navigation and major hydraulic structures on course. This chapter aims at providing an example of the extent of bed morphological changes downstream of the new Naga-Hammadi barrage as a result of controlled flow releases using 2D numerical modeling. A stochastic procedure is further presented that deals with the uncertainty emerging from scarcity of available measured data for sediment in the River Nile.

Keywords 2D model, Bed load, Naga-Hammadi barrage, River Nile, Suspended load

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On leave to German University in Cairo

A.M.A. Sattar (✉)
Irrigation and Hydraulics Department, Faculty of Engineering, Cairo University, Orman, 12316 Giza, Egypt
e-mail: ahmoudy77@yahoo.com

A.M. Negm (ed.), *The Nile River*, Hdb Env Chem (2017) 56: 171–186, DOI 10.1007/698_2016_91,

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1 Introduction

River morphology is a term that is used to describe how river channels change their shape and direction with time. The river changes happen at the bed and/or banks and affect river cross section and path. Morphological changes are mainly due to the interchange mechanism between bed sediment and suspended sediment, which cause erosion and deposition. These morphological changes occur all the time in the River Nile route (Fig. 1), which is considered the longest water route of sediment in the world. Sediment carried by river flow ranges from 10 to 100 kg/s for both bed and suspended loads.

Since the construction of the Aswan High Dam (AHD), suspended sediment load decreased from more than 100 million tons to less than 2 million tons annually [1]. With the presence of low intensity flows in the River Nile and the absence of the suspended sediment from upstream, the River Nile undergoes frequent bed

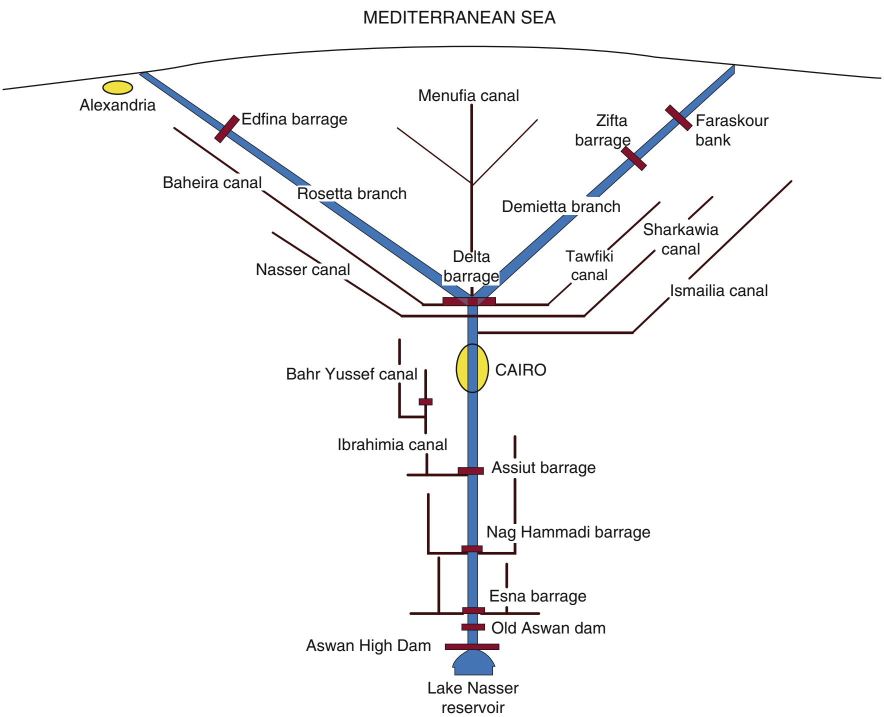


Fig. 1 Schematic of the River Nile and major barrages (www.Wikipedia.org)

morphological changes. However, scarce studies are available to address this important issue especially at locations where bed elevation change can have an adverse impact such as downstream of major barrages. Therefore, work in this chapter is presented as an example of required research in an important river for Egypt. A 2D depth averaged numerical model is utilized to model the bed geomorphological changes due to various river flows downstream (DS) of the new Naga-Hammadi barrage. This chapter is based on the author's work on the River Nile geomorphological changes and sediment processes analysis [1–5].

2 River Nile Flow

Since the construction of the AHD back in the 1960s, the Rive Nile flow has been controlled and maintained. Since no high floods can pass through the Egyptian part of the Nile, no significant changes in the bed morphology are expected. In the River Nile, the sediment processes, mainly erosion and deposition, are a function of stage and flow rate [1, 6]. Using stage hydrographs DS of Naga-Hammadi barrage, Fig. 2 shows that the peak flow has increased over past decade from 2,200 m^3/s to over 2,500 m^3/s, and the same is true for minimum river flow.

It has been reported in Sattar [1] that river flow with values higher than 2,300 m^3/s have more than 18% occurrence probability. With this in mind, there are possibilities that the peak flow through the River Nile will increase in the future especially during the 4 months of the high flow season. Predicting the bed morphological impacts of this expected flow can be useful for identifying potential impacts and planning mitigation. Using selected controlled releases from the Naga-Hammadi barrage of 3,700 and 4,700 m^3/s, the bed morphological changes in the reach DS the barrage are studied including the maximum permitted flow by the barrage spillway of 5,700 m^3/s. This high flow is stated by the Egyptian Ministry of Water Resources and Irrigation to flow through the River Nile without inundation of the side banks.

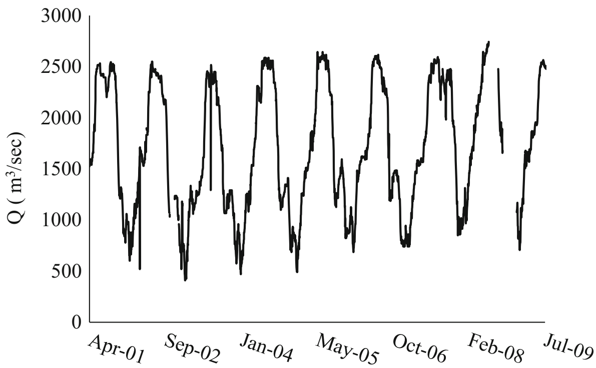


Fig. 2 Measured flow rate downstream of Naga-Hammadi barrage

3 Numerical Modeling of River Morphological Changes

With the River Nile route showing many meanders and curves, the secondary currents and associated patterns become very important with a significant impact on sediment processes. Therefore, a 2D model is necessary to capture these effects and their impacts on bed morphology. The 2D hydrodynamic-sediment models are based on the depth-integrated equations of motion and continuity linked to depth-integrated sediment transport models. A good 2D hydrodynamic-sediment model is capable of modeling sediment based on nonequilibrium bedload transport and suspended sediment transport. It deals with uniform and nonuniform bed material for both bedload and suspended load transport. It also accounts for bed changes and influence of the secondary flow on the sediment motion in curved channel. Although many 2D models exist, e.g., [7–13], three are widely used in engineering practical hydraulic problems. Models include MIKE 21 [14], CCHE2D [10], and TABS-MD [8]. MIKE 21 was developed by the Danish Hydraulic Institute. Similarly, TABS-MD has been widely used by the engineering community since its development in the early 1970s by the USACE Waterways Experimental Station. CCHE2D is a 2D hydrodynamic model for unsteady turbulent open channel flow and sediment transport simulations developed at the National Center for Computational Hydroscience and Engineering (NCCHE), the University of Mississippi, School of Engineering [10]. It was confirmed by [15] that CCHE2D model provides reliable and meaningful results compared to many other models and with equal accuracy as MIKE 21. Therefore, the 2D numerical model CCHE2D is applied in this study for simulating bed morphological changes in the River Nile.

4 Reach DS New Naga-Hammadi Barrage

4.1 New Naga-Hammadi Barrage

The Naga-Hammadi barrage is considered the biggest hydraulic structure built on the River Nile. It is located at Naga-Hammadi city at KM359.5 between 192 and 167 km reaches. Similar to other barrages on the River Nile, this barrage raises the upstream reach water levels so that an average of 50,000 km^2 of irrigated lands can receive water in addition to improving river navigation. With the increase of agricultural lands by 20–30% back in 2000 and the will to construct a new 64 MW power plant, a study in 1997 by Lahmeyer International recommended constructing a new barrage DS of the old one with a power plant. Water requirements and water level of Lake Nasser determine the annual flow through the Naga-Hammadi barrage. This flow is maximum during summer months (June, July, and August) with an average value of 2,200 m^3/s. The flow is minimum during winter months (December, January, and February) with an average value of 1,200 m^3/s. Emergency openings in the barrage allow for a maximum flood flow of 5,700 m^3/s and emergency flood of 7,000 m^3/s. The Lahmeyer study provided detailed assessments for the expected hydraulic and environmental impacts of the new barrage. All hydraulic assessments were made for the upstream reach and concentrated mainly on the backwater curve and increase in groundwater depth. However, no assessment of the bed morphological changes in the DS reach has been provided in the study despite their importance. The bed changes DS of the new barrage proved to be an important hydraulic issue even for low flow releases. After the new barrage was put in operation, the bed started to erode DS lowering the water levels and increasing the heading up on the barrage. For mitigation, a weir has been constructed to temporarily solve this issue [16].

4.2 Available Data

For assessing the bed morphological changes DS of the new Naga-Hammadi barrage, a reach 30 km has been chosen DS of the barrage. The reach extends from KM363 to El-Balyana gauging station at KM387. This reach (Fig. 3) has a couple of bends in the course of the river and contains two natural islands that are inhabited by people. Bed topography has been extracted from topographic maps surveyed by the Nile Research Institute during the years: 2003, 2010, and 2011 [1, 17]. Stage hydrographs from 1995 to 2010 US and DS study reach are obtained from gauge stations [1, 17]. Bed soil samples are available throughout the study reach revealing a weekly nonuniform nature of the riverbed with mean diameters of 1.315 mm (12%), 0.415 mm (70%), and 0.1315 mm (18%) for coarse, medium, and fine sand, respectively [1].

5 Deterministic Simulations of Riverbed Morphology

The study is discretized by a curvilinear grid with 3,000 nodes streamwise and 200 nodes in lateral with a total of 600,000 grids with average grid size of 8 m $\times$ 4 m. Knowing measured values of discharge and stage at selected gauge stations at

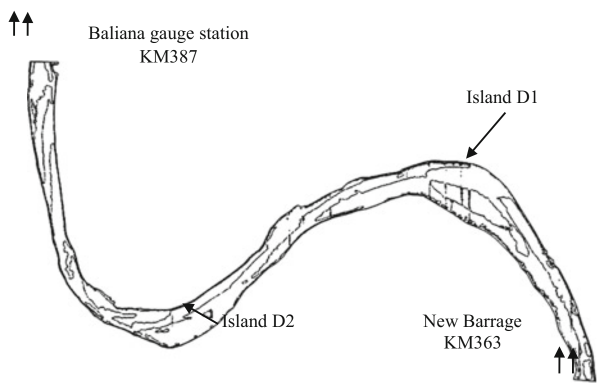
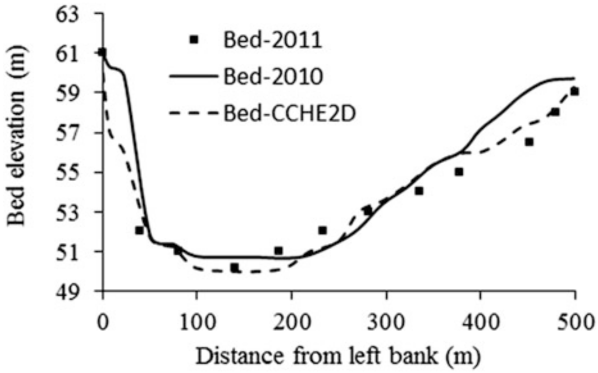


Fig. 3 Domain and topography for reach downstream of Naga-Hammadi barrage

Fig. 4 Numerical model calibration at KM365



KM363 and KM387, numerical model can be calibrated. This is achieved by using the measured discharge as input and matching the calculated stages with those measured. A standard k-epsilon turbulence model is used for turbulent resolution. Discharges ranging from 409 to 2,740 m^3/s were used for model calibration. Matching the calculated stage at the US boundary and at Balyana DS gauge station was accomplished with a 0.015 roughness coefficient.

Figure 4 shows the comparison between measured and calculated stages where average difference was calculated as 10 cm for all cases and 15 cm for low flood on January 2003. Once the hydrodynamic component of the model is calibrated, the sediment component is run to simulate bed changes over the year 2010 using measured bed changes between the years 2010 and 2011. Bed material was considered nonuniform with three classes obtained from samples at the Balyana station. The sand bed contains coarse, medium, and fine sand and 70% medium sand as discussed before. Total suspended load was considered in simulation with both bed load and suspended load considered. Measured concentrations are used as model inlet boundary [1, 17, 18]. Empirical factors in sediment relations were calibrated to match the calculated suspended sediment with that measured at Balyana station. Bedload adaptation length of 7.3 is considered and 0.04 for suspended sediment. Good agreement between measured and calculated bed topography is achieved as shown in Sattar [1] and demonstrated in Fig. 5.

5.1 Erosion and Deposition Patterns

For a steady flow of 3,700 m^3/s, the model was run to simulate the expected erosion and deposition patterns in the reach DS the new barrage. According to Sattar [1], the study reach has been divided into two regions, near-field and far-field regions. The near-field region extends to the island and the far-field takes the rest of the reach. The distribution of depth averaged velocity can be seen in Fig. 6. It is observed that the velocity started from an average value of 1 m/s DS the new barrage reaching to

Fig. 5 Measured and calculated stages at Balyana gauging station

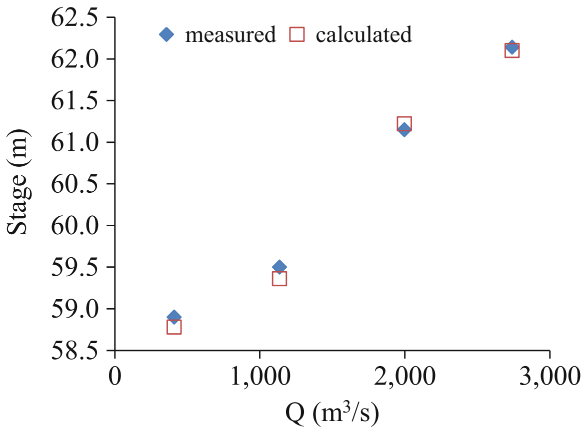
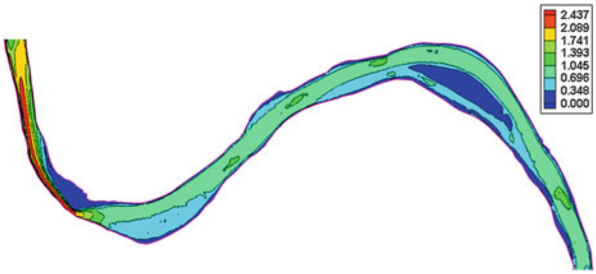


Fig. 6 Velocity distribution along study reach in m/s



more than 2 m/s at the end of the reach. Average velocity of 1 m/s has been calculated along channel course, while higher velocity values are calculated at the exit of second bend. The velocity at the first bend is calculated as 0.6 m/s due to the presence of an island that bifurcates the flow. In general, velocities in far-field part of the reach tend to be higher than those in the near-field due to the reduction of the river width from 550 m to less than 310 m.

Results of bed shear stress (shown in Fig. 7) showed a similar pattern of change within the reach analogous to velocity. An average shear stress value of 1.5 N/m^2 is calculated at the near-field, which increases to more than 5 N/m^2 at the exit of the second channel and continues with the reduction in channel width. Depth of erosion is calculated along study reach from 0.2 m to a maximum value of 2 m at reach bed. Maximum erosion occurred at the exit of second bend with a value of 2.2 m (Fig. 8). Moreover, deposition was calculated at locations of minimum velocity where the sediment carried by water flow settles to the bottom. Deposition quantities, as calculated by the numerical model, were in the same order of magnitude as erosion quantities. However, sediment deposition is calculated mainly at inner sides of bends and ranged from 0.4 m to a maximum value of 0.85 m at the second bend exit.

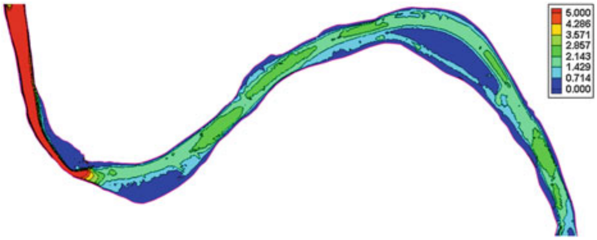


Fig. 7 Shear stress distribution along study reach in N/m^2

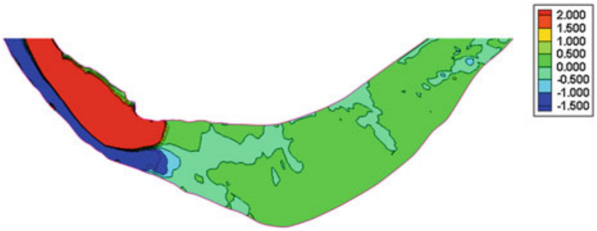


Fig. 8 Bed change at bend 2 showing erosion and deposition patterns

Table 1 Predicted erosion (10^3 m^3) in the near- and far-fields of the barrage, flow = 3,700 m^3/s, bed load = 0.01 kg/m/s, and suspended load = 0.01 kg/m/s

Date	Near-field erosion	Far-field erosion	Total erosion
29-May	0	0	0
13-Jun	53.25	148	201.25
28-Jun	106.5	296	402.5
13-Jul	146.25	401.5	547.75
28-Jul	186	507	693
12-Aug	224.5	579.5	804
27-Aug	263	652	915
11-Sep	289	707	996
26-Sep	315	762	1,077

Table 1 shows the volumes of sand eroded in the study reach with bed load 0.01 kg/s and suspended load 0.01 kg/s used as model inputs. It is shown that during flood season, the volumes of bed sand eroded are higher than those of low flow season. The increase in erosion volume with increase in flow is more obvious at the beginning of the flooding season (May) and tends to decrease afterwards. Moreover, erosion in the far-field of study is larger than that in the near-field.

5.2 *Bed Level Changes*

Erosion DS the new barrage has proven to be a critical issue regarding the design of the barrage where DS erosion would lower the DS water level and thus increase the difference between upper and lower levels. This difference is known as heading up. Numerical simulations for various flows showed that the erosion DS of the barrage leads to changes in the bed levels staring from −0.1 m for 3,000 m^3/s to −1.2 m for 5,000 m^3/s. Thus, the DS water levels shall drop with the same values of bed lowering and shall increase heading up with the same values. The changes in bed levels were calculated by the numerical model for 120 days to simulate complete high flow season. However, real cases would have successive flow during the whole year with cumulative erosion effects on the barrage DS. This would lead to various future problems that need to be addressed. It is to be noted that Sattar [1] reported that the designed maximum heading up for the new barrage is 7.5 m and showed that this design condition starts to be violated above 3,000 m^3/s flow.

5.3 Navigation Conditions Changes

For flows staring from 3,000 m^3/s, the safe navigation requirements of the Nile Transport Authority regarding a 0.8 m/s maximum averaged velocity start to be violated. For a large variety of cargo containers, velocities exceeding the specified limit shall prohibit them from navigation. The calculated depth averaged velocity is shown in Fig. 9 along the study reach for high flow of 3,700 m^3/s during high flow season. The average velocity along the channel course is 1.2 m/s and increases to reach 2.5 m/s at the exit of the second bend. On the other hand, higher flows produce higher velocities reaching 3.5 m/s for 4,700 m^3/s. These results imply that for high flows, it would be not safe for river transport authorities to operate cargo ships.

An additional requirement for safe cargo ship navigation in the River Nile is the presence of a minimum water depth of 2.3 m. The bed morphological changes produced by passing high flows did not have a significant impact on the available navigation depths. Even though significant deposition is calculated at the exit of the second bend, this happens only at the right side of the reach leaving the left side with sufficient navigation depth. When passing low flows, the 2.3 m minimum depth requirement is not met and water depths reach as low as 1.7 m. Due to a decrease in velocity, sediment carried by the flow tends to deposit and this occurs

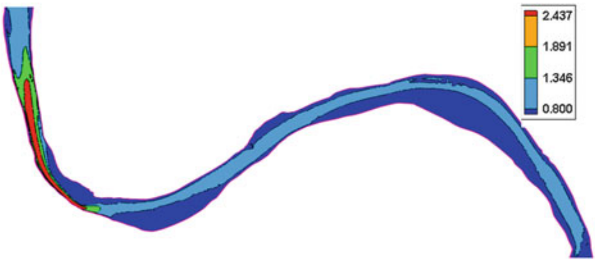


Fig. 9 Velocity contours above allowable safe navigation limit of 0.8 m/s for flood of 3,700 m^3/s

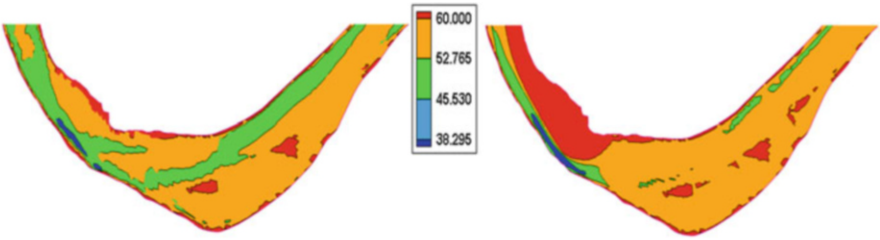


Fig. 10 Bed elevations before and after passage of 3,700 m^3/s flood for 4 months

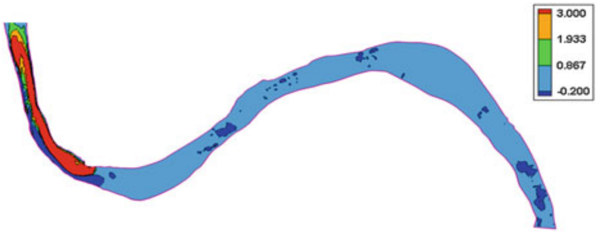


Fig. 11 Bed level change along study reach in kg/s using uniform sediment (flow = 3,700 m^3/s)

with high values at the left side of the river reach at the exit of the second bend. These deposits tend to narrow the available width of the river for cargo navigation. Figure 10 shows the bed elevations before and after passage of 3,700 m^3/s. The deposition is shown clearly to have increased bed elevation from +55 to +60 when the water exits bend 2. Also, the width of the available navigable watercourse has decreased significantly by more than 50 m. This effect starts to be obvious in calculations after the first month of simulations.

5.4 *Effect of Bed Material Uniformity*

Field measurements determined the initial bed material size distribution as discussed before. This bed material composition was measured after high flow season during normal steady flow conditions. However, simulation of higher flood releases would dramatically change the material composition and thus would have a pronounced impact on the bed morphology. Figures 11 and 12 show the bed level changes in case of uniform sediment (Fig. 11) and in case of nonuniform sediment (Fig. 12).

In case of various sediment classes of riverbed, the flow entrains the finer class of sediment. The entrained fine sediment is deposited at the exit of the second bend when stream velocity drops below critical values, leading to more deposition. Therefore, the interaction between water and sediment classes caused more erosion in the near-field and more deposition in the far-field regions of the reach. This result

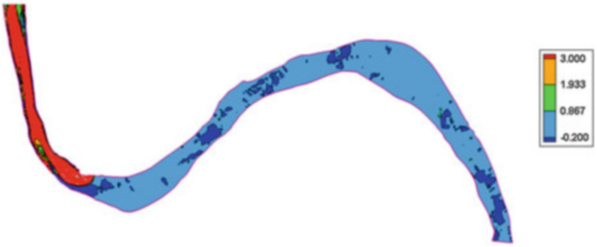


Fig. 12 Bed level change along study reach in kg/s using nonuniform sediment (flow = 3,700 m^3/s)

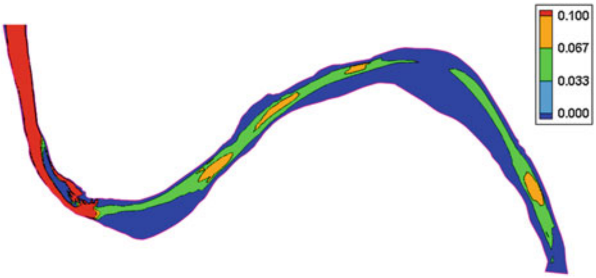


Fig. 13 Bedload transport along study reach in kg/s using uniform sediment (flow = 3,700 m^3/s)

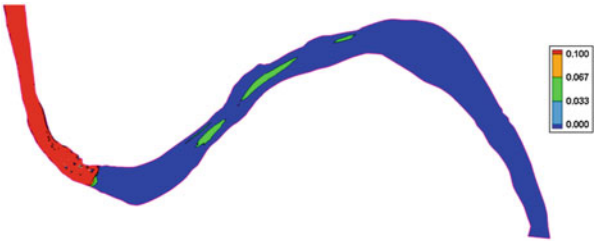


Fig. 14 Bedload transport along study reach in kg/s using nonuniform sediment (flow = 3,700 m^3/s)

is confirmed by bedload transport distribution along reach presented in Fig. 13 for uniform bed sediment and in Fig. 14 for nonuniform bed sediment. Bedload transport has an average value of 0.012 kg/s in the case of nonuniform sediment along the near-field, while this value increased to an average of 0.04 kg/s in case of uniform sediment. This higher value of bed transport caused less erosion holes throughout the reach. However, in far-field, the bedload transport in case of nonuniform sediment had values more than 0.15 kg/s following the exit of the second bend causing more deposition, which covers more than 80% of that region compared to around 60% of the region in case of uniform sediment.

Due to the mutual interaction between the flow and fine sediment class (class 1), Fig. 15 shows the final composition of bed material for fine sediment after deposition and erosion processes. The fine sediment has been completely removed by flow from all parts of the near-field bed where its percentage in the bed material shows a zero value. This fine sediment has been transported by flow and deposited in the far-field region at places of low velocity where bed composition becomes

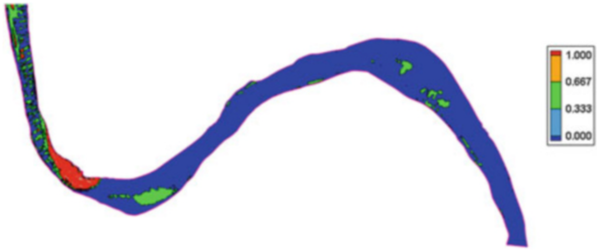


Fig. 15 Final bed composition in percentage for class 1 nonuniform sediment (flow = 3,700 m^3/s)

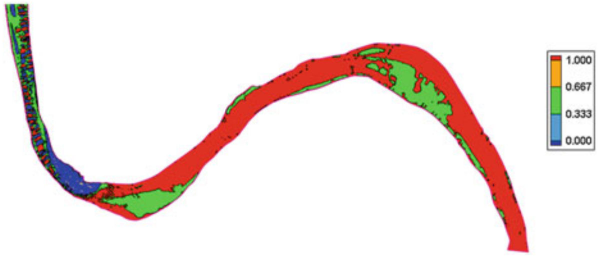


Fig. 16 Final bed composition in percentage for class 2 nonuniform sediment (flow = 3,700 m^3/s)

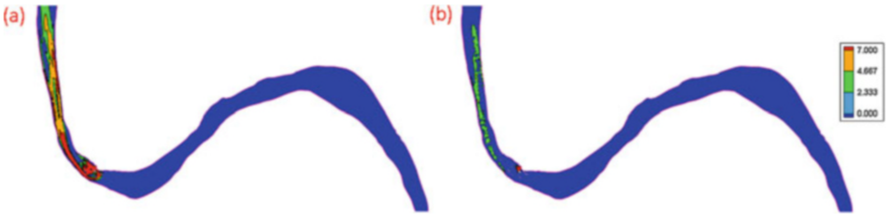


Fig. 17 Bedload fractional transport rate (kg/s) for: (**a**) class 1, (**b**) class 2 sediment (flow = 3,700 m^3/s)

mainly 100% fine sediment. For coarse and medium size sediment (Fig. 16), their percentage in the bed increased from 12% and 70% initially to more than 80% after flow passage during high flow season. Their percentage decreased at locations with calculated high deposition, which has been mainly caused by fine sediment. Results in Fig. 17 show clearly that the fine sediment quantities that are carried by flow constitute a high percentage of bedload transport in case of nonuniform sediment, thus impacting the patterns of erosion and deposition.

This confirms that initial bed size classes are quite delicate and unforgiving when it comes to modeling erosion/deposition and especially bedload transport [19] and shows that it is important to consider bed material nonuniformity in modeling bed morphological changes and suggests that relying on the slightly nonuniform nature of the River Nile bed sediment might not be a good choice. This assumption lacks the real representation of bed material and accordingly the real interaction between flow and bed/suspended sediment. This interaction is accounted mainly due to particle diameter, related flow critical parameters, and the exchange between bed, bed load, and suspended load along the channel, which is now crudely, represented resulting in a cruder unrealistic mechanism of interaction [1].

6 Stochastic Simulations of Riverbed Morphology

Despite the importance of many input parameters in numerical modeling of riverbed geomorphic simulations, measurements are scarcely found. Moreover, comparing measured data for close river sections, Sattar [1] showed some discrepancy in values. Therefore, a big deal of uncertainty is always available in input parameters to bed morphological numerical models not to mention the uncertainty imposed by the used empirical formulae, such as bed transport formula. One way to deal with this uncertainty is through using Monte Carlo simulation (MCS). This is a numerical technique used to calculate the output uncertainty of a model. The method is robust and easy to implement; it can also handle different distribution types and always be implemented in a straightforward manner [20–27]. The uncertainty in the numerical model can be assumed to be due to uncertainty in input parameters [1] mainly: bed load, suspended load, and median grain size and adaptation length for bed load.

The MCS shall be applied using the following procedure:

- The uncertain parameters are fitted to a probability distribution chosen based on set of scores
- Random combinations of uncertain parameters are selected from relevant probability distribution functions (PDF)
- A set of deterministic samples are entered to the numerical model to make a deterministic run for each of the chosen flows
- Model output morphological changes are stored for the deterministic run
- This procedure is repeated for a specified number of realizations
- Instead of having a discrete output, now there are a large number of outputs equal to the chosen MC realizations
- With a sufficiently large number of realization, the output distribution function can be plotted and distribution parameters extracted

Measurements of bed load and suspended load are obtained from Nile Research Institute and Abdel-Fattah et al. [17, 18]; adaptation length values are collected from the literature [1]. Fitting the available data to PDFs yielded generalized extreme value (GEV) distribution with highest scores in Kolmogorov–Smirnov and Anderson–Darling tests. Random variables that cannot exist in real rivers

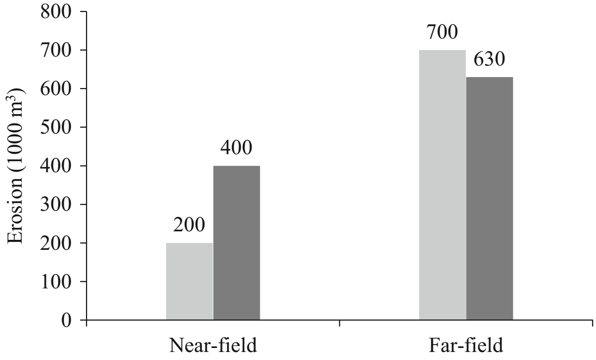


Fig. 18 Erosion in near-field and far-field as calculated by deterministic run and stochastic one

have been excluded using truncated GEV distributions. Choice of the number of realizations has been based upon the convergence of variance of the model output. This output used to probe the MCS convergence has been chosen to be erosion depth at the DS of the new barrage. It is found that the MCS starts to converge after 2,500 realizations [1] and thus a fair representation of the variance can be achieved.

The results of MCS are presented in Fig. 18 for flow of 3,700 m^3/s compared to those obtained by running the model as single deterministic run using mean values of parameters. The mean value for erosion in the near-field was calculated by MCS to be double that of a single deterministic run, while results for both average depth average velocity and heading up showed close values between deterministic and stochastic runs. Utilizing the least square linearization and the MCS, the contribution of each of the input parameters (bed load, suspended load, median diameters, and adaptation length) to the erosion output was assessed by Sattar [1]. Results showed that the adaptation length has the least contribution to uncertainty of results of 2D sediment model as it contributes with a maximum value of 3% in all selected flows. Other input parameters, suspended load, bed load, and median grain diameter, contributed more to the calculated erosion volumes with various percentages according to simulated flow. However, the suspended sediment load remains the largest contributor to uncertainty in erosion followed by the bed load [1].

7 Conclusions

The River Nile is the longest sediment path in the world and exhibits various processes (erosion and deposition) that continuously change its bed morphology. This work applied a 2D numerical model to simulate the bed changes DS the new Naga-Hammadi barrage due to controlled possible flows. Bed morphological changes were simulated and velocities have been computed. Due to the uncertainty in input parameters (bed load, suspended load, median grain diameter, and adaptation length), MCS was utilized to simulate the uncertainty in model calculations. Results of MCS simulations showed difference in mean values of erosion than single deterministic runs using mean value of parameters. However, the velocity and heading-up DS the barrage had similar values in MCS and deterministic runs. Results show the importance of bed morphological simulations and show the requirement of having stochastic runs to supplement the usual deterministic analysis.

References

1. Sattar A (2014) Predicting morphological changes ds new Naga-Hammadi barrage for extreme Nile flood flows: a Monte Carlo analysis. J Adv Res 5(1):97– 107
2. Foda A, Sattar A (2013) Morphological changes in river Nile at Bani-Sweif for probable flood flow releases. In: Proceedings of the international conference on fluvial hydraulics, RIVER FLOW 2014, Switzerland
3. Sattar A (2013) Using gene expression programming to determine the impact of minerals on erosion resistance of selected cohesive Egyptian soils. In: experimental and computational solutions of hydraulic problems, part of the series GeoPlanet: earth and planetary sciences, pp 375–387
4. Sattar A (2014) Gene expression models for prediction of dam breach parameters. J Hydroinf 16(3):550–571. IWA
5. El-Hakeem M, Sattar A (2015) An entrainment model for non-uniform sediment. Earth Surf Process Landf 4(9):1216–1226. doi:10.1002/esp.3715
6. Gessler D, Hall B, Spasojevic M, Holly F, Portaheri H, Raphelt N (1999) Application of 3D mobile bed, hydrodynamic model. J Hydraul Eng 125(7):737–749, ASCE
7. Spasojevic M, Holly F (1990) MODEB2 numerical simulation of two dimensional mobile bed processes. Technical Report No 334, Iowa Institute of Hydraulic Research, University of Iowa, Iowa city, Iowa
8. Thomas WA, McAnally WH (1985) User's manual for the generalized computer program system open channel flow and sedimentation-TABS-2. Instruction Report HL-85-1, Waterways Experiment Station, U.S. Army Corps of Engineers, Vicksburg, USA
9. Van Rijn LC (1987) Mathematical modeling of morphological processes in the case of suspended sediment transport. PhD Thesis, Delft University of Technology, The Netherlands
10. Jia Y, Wang S (1999) Numerical model for channel flow and morphological change studies. J Hydraul Eng 125(9):737–749, ASCE
11. Olsen N (1999) Two dimensional numerical modeling of flushing processes in water reservoirs. J Hydraul Res 37(1):3–16
12. Brors B (1999) Numerical modeling of flow and scour at pipelines. J Hydraul Eng 125 (5):511–523, ASCE
13. Nagata N, Hosoda T, Muramoto Y (2000) Numerical analysis of river channel processes with bank erosion. J Hydraul Eng 126(4):243–252, ASCE
14. DHI Inc. (2003) 301 http://www.dhisoftware.com. South State Street, Newtown, PA 18940, USA
15. Scott SH (2002) Evaluation of selected two dimensional hydrodynamic and sediment transport numerical models for simulation of channel morphology change. Technical Note, Flood Damage Reduction Research Program
16. Lahameyer International (LI) (1997) Technical study for feasibility to construct new Naga-Hammadi Barrage. Ministry of Water Resources and Irrigation, Barrages Sector, Egypt
17. Nile Research Institute (2011) Engineering library reports. Central Library. National Water Resources Center, Kanater, Egypt
18. Abdel-Fattah S, Amin A, Van Rijn LC (2004) Sand transport in Nile River, Egypt. J Hydraul Eng 130(6). ASCE

19. American Society of Civil Engineering, ASCE (2010) Sedimentation engineering, Manual # 110, Edited by M. Garcia
20. Sattar A, Gharabaghi B (2015) Gene expression models for prediction of longitudinal dispersion coefficient in streams. J Hydrol 524:587–596
21. Sattar A (2014) Gene expression models for the prediction of longitudinal dispersion coefficients in transitional and turbulent pipe flow. J Pipeline Syst Eng Pract 5(1):04013011. ASCE
22. Najafzadeh M, Sattar A (2015) Neuro-Fuzzy GMDH approach to predict longitudinal dispersion in water networks. Water Resour Manag 29:2205–2219. doi:10.1007/s11269-015-0936-8
23. Sattar A, Gharabaghi B, McBean E (2016) Prediction of timing of watermain failure using gene expression models. Water Resourc Manag 30(5):1635–1651
24. Sattar A (2016) Prediction of organic micropollutant removal in soil aquifer treatment system using GEP. J Hydrol Engineering 21(9). doi:10.1061/(ASCE)HE.1943-5584.0001372. ASCE
25. Sattar AM (2016) A probabilistic projection of the transient flow equations with random system parameters and internal boundary conditions. J Hydraul Res 54(3):342–359. doi:10.1080/00221686.2016.1140682
26. Thompson J, Sattar AM, Gharabaghi B, Richard W (2016) Event based total suspended sediment particle size distribution model. J Hydrol 536:236–246. doi:10.1016/j.jhydrol.2016.02.056
27. Sabouri F, Gharabaghi B, Sattar AMA, Thompson AM (2016) Event-based stormwater management pond runoff temperature model. J Hydrol 540:306–316. doi:10.1016/j.jhydrol.2016.06.017

Distribution of Natural Radioactivity in the Egyptian Part of the Nile River from Aswan to El-Minia

Ayman A. El-Gamal

Abstract Ionizing radiation has sufficient energy to ionize molecules and has different forms such as electromagnetic waves (gamma and X-rays) and high-energy particles (alpha and beta). Background radiation is the natural level of radioactivity from the environment such as from cosmic radiation. According to the IAEA, soil typically contains the following four natural radioisotopes: ^{40}K as single occurrence, ^{226}Ra, ^{238}U, and ^{232}Th as radioactive series. Different measurements of natural radioactivity were executed in the sediments of the Upper Egypt part of the Nile River. The ranges and average activity concentrations of the detected radionuclides ^{226}Ra (^{238}U), ^{232}Th, and ^{40}K were 3.82–34.94 (16.3), 2.88–30.10 (12.9), and 112.31–312.98 (200.21) Bq/kg, respectively, during 2007 according to El-Gamal and his group. Also, their ranges and concentrations were 13–42 (29), 10–67 (45), and 74–139 (123) Bq/kg, respectively, during 2012 according to El-Taher and Abbady and 7–188 (50.6), 8–117 (41.3), and 47–412 (242.8) Bq/kg, respectively, during 2013 according to Issa and his group. El-Gamal and his group detected the range of the total absorbed dose rates during 2007 from 12.71 ± 0.96 to 38.17 ± 1.55 nGy/h with average 24.17 ± 7.3 nGy/h.

Keywords Natural radioactivity, Nile River, Sediments, Upper Egypt

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A.A. El-Gamal (✉)
Coastal Research Institute, National Water Research Center, 15, El-Pharaana Street, El-Shallalat, 21514 Alexandria, Egypt
e-mail: ayman_elgamal@yahoo.com

A.M. Negm (ed.), *The Nile River*,
Hdb Env Chem (2017) 56: 187–206, DOI 10.1007/698_2016_94,

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1 Introduction

1.1 Ionizing Radiation

Ionizing radiation has sufficient energy that can ionize an atom and is part of the chemical composition of many things including biological and other systems.

Ionizing radiation can take two different forms: (1) electromagnetic waves, which spread out in all directions through space at the speed of light, and (2) high-energy particles, which travel through space at various rates [1]. The three main types of ionizing radiation are alpha and beta particles and gamma rays. Figure 1 shows the shielding of each of them.

Alpha (α) particles are the most energetic of the three types of ionizing radiation. They can travel only centimeters in the air. The range of an alpha particle of 5.5 MeV energy is about 4 cm in air. Alpha particles lose their energy almost as soon as they collide with anything. It can be stopped easily by a sheet of paper or the human skin.

Beta (β) particles are much smaller than alpha particles. Most beta energies are less than 1 MeV, but there are a few higher-energy beta particle emitters. The range in air of a beta particle of 1.710 MeV energy is about 650 cm. Beta particles can pass through a sheet of paper, but it can stopped by a thin sheet of aluminum foil or glass.

Gamma (γ) rays, unlike alpha or beta particles, are waves of electromagnetic energy. Gamma rays travel at the speed of light (about 300 km/s). Gamma radiation

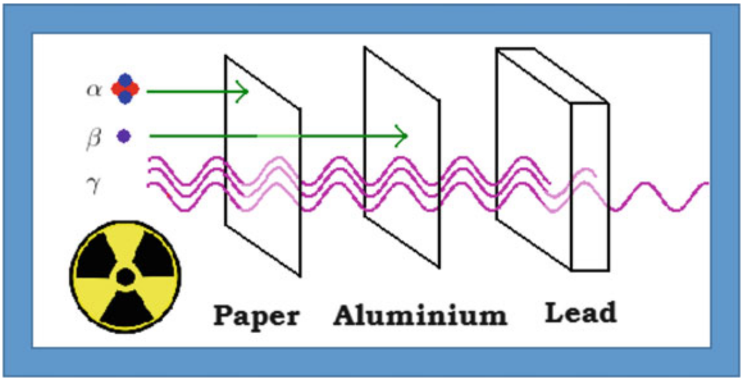

Fig. 1 Shielding of alpha, beta, and gamma radiation

has very high penetrating power, and it can penetrate even through lead and concrete. Gamma-ray shielding requires high quantity of mass.

1.2 Radioactive "Half-Lives"

The radioactivity of a material decreases with time. The time that it takes a material to lose half of its original radioactivity is referred to as its half-life. Each radioactive element has a characteristic half-life. The half-lives of various radioactive elements may vary from a second to millions of years [2].

1.3 Definitions and Units

The International System of Unit (SI) for measuring the amount of radioactivity is the becquerel (Bq), where the old unit was curie (Ci).

$$1\,\text{becquerel} = 1\text{radioactive decay per second} = 2.703 \times 10^{-11}\text{Ci}.$$

The radiation dose expressed the magnitude of radiation exposures as three expressions according to the nature of the receiving medium or body [3]:

1. The exposure unit, which expresses the amount of radiation dose in air, and it is defined as the amount that will produce, under normal conditions of pressure, temperature, and humidity, in 1 kg of air, an amount of positive or negative ionization equal to 2.58×10^{-4} coulomb.
2. The *absorbed dose*, which expresses the amount of energy deposited in a unit mass in media other than human. The SI unit is the gray (Gy), which is equivalent to [1 J/kg], and the old unit was the *rad*, 1 gray = 100 rad.

3. The dose equivalent, which expresses the amount of energy deposited in a unit mass in human tissue. The SI unit is the *sievert* (Sv). This dose reflects the fact that the biological damage caused by a particle depends not only on the total energy deposited but also on the rate of energy loss per unit distance traversed by the particle (or "linear energy transfer"). The old unit was rem, 1 Sv = 100 rem.

1.4 Sources of Ionizing Radiation Exposure

There are many diverse sources of exposure to ionizing radiation and conditions in which persons can be exposed. Exposures can result from natural sources, such as radioactive materials that exist in the soil, and from cosmic rays. Workers can also be exposed to radiation from sources that result from human activities. For example, exposure to ionizing radiation can result from naturally occurring radioactive material (NORM) or from equipment that emits radiation such as X-ray devices.

1.5 Radiation Background

Humans can be exposed to the natural radioactivity from the environment. A primary source of external exposure is cosmic radiation from the sun, mostly in the form of low-level gamma radiation. Exposure rates increase with increasing altitude. Other exposure comes from naturally occurring radioactive materials (NORM) that are found in the earth's crust (e.g., uranium, thorium, and radon). Everyone is exposed to small amounts of radiation (gamma radiation, alpha and beta particles) that result from these radionuclides and their decay products. The amount of exposure to naturally occurring sources varies widely because the level of radioactivity in soil or water in different locations varies. Along with external exposures, people are exposed internally by eating foods and drinking water containing NORM. Sludge, drilling mud, and pipe scales are examples of materials that often contain elevated levels of NORM. Figure 2 shows the background radiation sources.

Technologically enhanced naturally occurring radioactive materials (TENORM) are created when industrial activity enhances the concentrations of radioactive materials or when the material is redistributed as a result of human intervention or industrial processes, and this can result in increased worker exposures. TENORM can result from manufacturing processes, such as the production of materials and equipment from raw materials that contained NORM, and concentrations of these materials are sometimes increased as a result of these processes.

In addition to NORM and TENORM, occupational exposures can result from operation of atomic facilities for medical, research, or industrial purposes. Equipment that produces ionizing radiation is another source of workplace exposure such as X-ray equipment and electron microscopes [4].

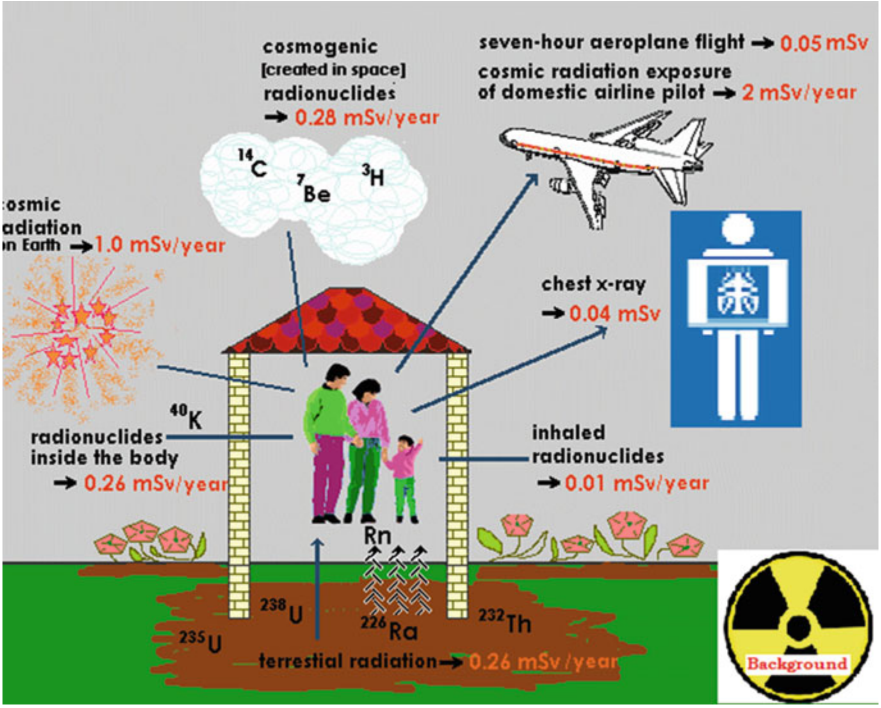

Fig. 2 The background radiation sources

1.6 Radiation Detection

Ionizing radiation cannot be detected by human senses. However, ionizing radiation can measure and monitor, in general, with simple scientific instruments such as dosimeters, film badges, and Geiger counters. People who routinely work with or around radiation sources wear dosimeters such as thermoluminescent dosimeters (TLD) or film badges which contain a piece of film that is sensitive to radiation. These badges are read regularly to determine a worker's total exposure to radiation over a period.

There are three main radiation detector categories:

- Gas-filled detectors
- Scintillation detectors
- Semiconductor detectors

1.6.1 Gas-Filled Detectors

A gas-filled detector is a tube composed of enclosed gas between two electrodes (anode and cathode) where there is a potential difference. When radiation passes through the tube, it interacts with the gas atoms and molecules; atom excitation and ionization occur causing an electrical pulse. The pulse can be measured on a meter, and it depends on the energy deposited during radiation gas interaction. A Geiger counter is an example of the gas-filled detector.

1.6.2 Scintillation Detectors

The interaction of different radiations with a scintillator will ionize and excite its atoms and molecules. After a short time, a small percentage of the deposited energy will be released due to scintillator atom de-excitation that produces fluorescence light, visible light pulses, known as scintillation. The light pulses (scintillations) are converted to photoelectrons that are magnified through the photomultiplier tube to electric signals. Radiation detection systems based on scintillation detectors consist of four main components: scintillator (the sensitive detector), optical coupling system, photomultiplier tube, and signal possessing electronic.

1.6.3 Semiconductor Detectors

Semiconductors are materials that neither have enough free charge carriers to behave as electrical conductors nor have high resistivity like electrical insulators. The solid crystal has three energy bands that are valence band, conduction band, and forbidden band. The semiconductor materials, the forbidden energy band is relatively narrow to prevent the movement of the electron to conduction band with the variation of temperature. The conductivity of the semiconductors is zero. The conductivity of semiconductors increases with increasing the concentration of impurities, which create new energy levels that facilitate the movement of the carrier within the crystal. The group IV elements silicon and germanium are the most widely used semiconductor crystal as radiation detectors. Practically both Ge and Si photon detector are cooled down with liquid nitrogen during operation to reduce the thermal charge carrier generation (noise) to acceptable limit.

The most important detection media for gamma-ray spectrometry are inorganic scintillator and semiconductors such as hyperpure germanium (HPGe) detectors. Gamma-ray spectrometry based on HPGe detector is preferred for the determination of radionuclides in food and environmental samples because of its higher resolving power. The preamplifier is located near the detector as part of the cryostat package to reduce electronic noise. There are different types of germanium detector such as coaxial, planar, and well.

1.7 Quality Control

The proof of the quality and reliability for environmental radioactivity measurements is an important issue and a basic requirement. This requires a sophisticated system of quality assurance and control [5]. A first requirement is that the purpose of the measurement is defined and thereby appropriately measured. The quality of a measurement starts with the experimental design, sampling strategy, sampling methods, and their documentation. The determination of characteristic limits is the general approach for the evaluation of uncertainties. This does not only apply to radioactivity measurements but can be easily extended to any analytical measurement where a measure of quantity in a sample has to measured against a background or blank of the general environment [6]. The determination of characteristic limits according to the cited standards is straightforward, and only in some cases, such as in gamma spectrometry, some more sophisticated mathematical methods have to be applied [7].

To demonstrate accuracy and reliability, repeated analyses of reference materials and frequent participation in interlaboratory comparisons are essential. Large efforts have been undertaken to establish reference materials such as the intensive work done by the IAEA and many national and international institutions.

2 Natural Radioactivity

Radioactivity is present everywhere and has been since the formation of the earth. According to the IAEA, soil typically contains the following four natural radioisotopes: ^{40}K, ^{226}Ra, ^{238}U, and ^{232}Th. In one kilogram of soil, the potassium-40 amounts to an average 370 Bq of radiation, with a typical range of 100–700 Bq; the others each contribute by 25 Bq, with typical ranges of 10–50 Bq (7–50 Bq for the ^{232}Th). Some soils may vary greatly from these norms [8].

Of the many radionuclides that must have been present when the earth was created about 4,500 million years ago, only the long-lived ones are still present today. The most important of these, as far as the natural radiation dose is concerned, are ^{40}K and the members of the decay series headed by ^{238}U and ^{232}Th [9].

2.1 Uranium and Thorium Series

From an environmental point of view, two radioactive decay series or decay chains are dominant in nature and account for most of the natural radioactivity of terrestrial origin. These two dominant chains are the uranium and thorium series, which are headed by ^{238}U and ^{232}Th, respectively [10].

Uranium series includes very important radionuclides such as ^{226}Ra, ^{222}Rn and ^{222}Rn daughters, and ^{230}Th. Thorium series is also very important as it includes the radioactive isotope of the inert gas radon, ^{220}Rn. ^{222}Rn and ^{220}Rn are the most significant contributors to the lung dose from inhaled uranium dusts [11]. The two radioactive decay chains are found in the earth's crust with varying concentrations from one location to another and depend significantly on the geological formation of the earth's crust. The earth's crust has over a hundredfold variation in its concentration of K, Th, and U [10, 12]. The three radionuclides tend to concentrate in a variety of ways to produce different types of radioactive anomalies that are important in calculation dose concentration. The major anomalies in the concentrations of radioactive minerals in soil are:

1. Monazite sand and other placers
2. Alkaline intensive and granites
3. Bauxite and intensity-weathered soils
4. Ground waters enriched in uranium
5. Black shales and related organic accumulation

In Egypt, monazite black sand deposits are extensive, along the beaches of Rashid on the northeast coast of the Mediterranean Sea [13].

2.2 Single Occurrence ^{40}K

At least 22 natural single or non-series primordial radionuclides have been identified. Most of these have such long half-life and small biological affect so they are of little significance in terms of environmental dose. The most important single occurrence radioisotope from a biological standpoint is ^{40}K.

Potassium, which is a member of the highly reactive Group IA alkali metal family of elements, has many isotopes [14] with different mass numbers. Only ^{40}K is radioactive and has $T_{1/2}$ 1.3e9 years. As potassium is essential to life, ^{40}K is found in all living organisms. The characteristic energy of ^{40}K is 1.460 MeV. This photon is highly useful for identification and quantification of ^{40}K by gamma spectrometry making an excellent calibration point.

3 Black Sand

The decomposition products of the mountain ranges of Sudan and Abyssinia have been carried out through the course of the Nile River during the last 10,000 years of recent period and subjected to natural separation and sorting during transportation. The floodwaters have deposited these erosional products seasonally year after year, over the older mixture of mud and sand [15]. The Egyptian black sands are beach placers deposited from the Nile silt reaching the Mediterranean Coastal Plain at the

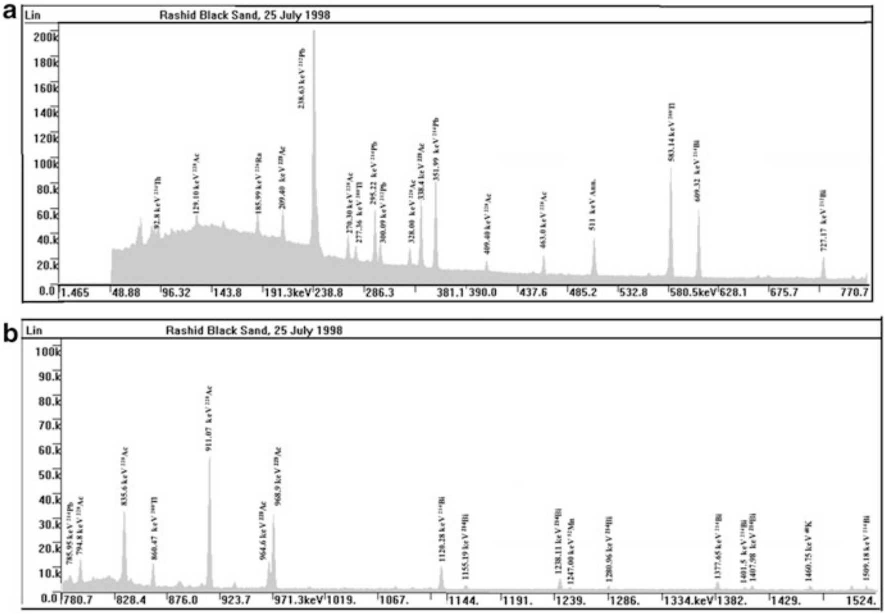

Fig. 3 (**a** and **b**) Radioactive gamma spectrum of Rosetta black sand (collected during 1998) measured by gamma spectrometer with HPGe detector [18]

river mouths. It contains many mineral species as they have been derived from igneous and metamorphic rocks. These sediments contain heavy minerals which are required for the industrial exploitation whether for nuclear industry or other metallurgical and engineering industries. Black sand deposits are extensive, along the beaches of Rashid on the northeast coast of the Mediterranean Sea [13, 16]. The mineral constituents include six heavy economic minerals, namely, magnetite, ilmenite, monazite, zircon, rutile, and garnet. Monazite, zircon, and rutile minerals contain a number of elements necessary for the nuclear industry, e.g., uranium, thorium, zirconium, hafnium, titanium, and rare earth elements [17]. El-Gamal presented the gamma spectrum of Rosetta black sand (collected during 1998) as shown in Fig. 3 [18].

4 Pathways of Radioisotopes to Aquatic System (Rivers)

An exposure pathway is the link between environmental releases and local populations that might meet into contact with, or be exposed to, environmental contaminants. An exposure pathway evaluation, therefore, determines if site contaminants have been, are, or will be in contact with local populations. The following diagram (Fig. 4) illustrates the potential pathways of radionuclides released into the environment in the uncontrolled manner in water [19].

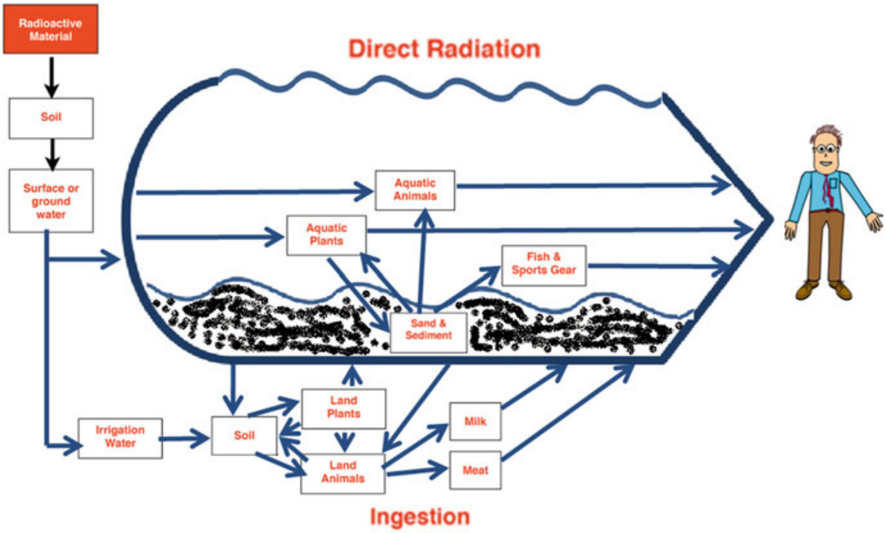

Fig. 4 Pathways for radiation migration through soil and water

5 Distribution of Natural Radioactivity in the Upper Egypt Nile River

5.1 ^{238}U, ^{232}Th, and ^{40}K Activity Concentrations

The average activity concentrations of the detected radionuclides ^{238}U, ^{232}Th, and ^{40}K in the Nile River sediment samples during 2007 according to El-Gamal and his group were 16.30 ± 9.22, 12.9 ± 6.23, and 200.21 ± 52.94 Bq/kg, respectively. The sites of study are presented in Fig. 5. Their ranges were 3.82 ± 1.54–34.94 ± 4.01, 2.88 ± 1.07–30.10 ± 1.83, and 112.31 ± 4.77–312.98 ± 12.24 Bq/kg, respectively [20].

El-Taher and Abbady [21] detected the gamma radioactivity concentration of ^{226}Ra as represented to ^{238}U, ^{232}Th, and ^{40}K using the gamma spectrometer in the Upper Egypt from Aswan to El-Minia during 2012. Their ranges and mean values in brackets were 13–42 (29), 10–67 (45), and 74–139 (123) Bq/kg, respectively.

Issa and his group studied the natural radioactivity in El-Minia region of Nile River [22]. The average gamma radioactivity concentration values of ^{226}Ra as represented to ^{238}U, ^{232}Th, and ^{40}K in Minia region were 7–188 (50.6), 8–117 (41.3), and 47–412 (242.8) Bq/kg, respectively.

Different measurements of natural radioactivity were executed for the Upper Egypt part of the Nile River and their results are presented in Table 1. The Egyptian data were compared with the national and international data as listed in Table 1.

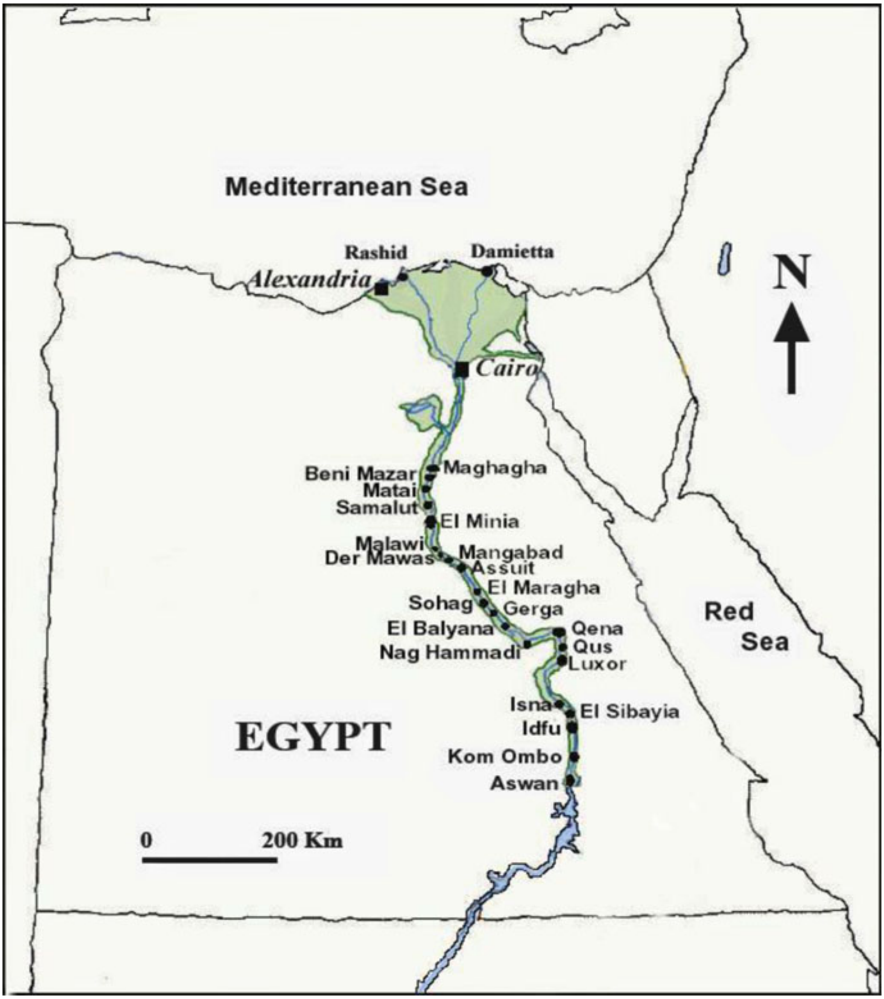

Fig. 5 Map represents Nile River sites under investigation in the Upper Egypt [20]

6 Division the Area of Interest into Four Regions [20]

El-Gamal and his group divided the Nile River from El-Minia to Aswan into four sections according to the presence of the barrages on the Nile River as shown in Fig. 6. The sedimentation process and the flow of the Nile water are highly affected by these barrages.

Table 1 Comparison of radioactivity concentration (range and mean in Bq/kg) of the Upper Egypt Nile sediments with other areas of the world

Location	^{226}Ra (^{238}U)	^{232}Th	^{40}K	Reference
Upper Egypt 2006	52 ± 7.3	76.2 ± 6.2	351.9 ± 17.6	Uosif [23]
Upper Egypt 2007	3.82–34.94 (16.3)	2.88–30.1 (12.9)	112.31–312.98 (200.21)	El-Gamal et al. [20]
Upper Egypt 2012	13–42 (29)	10–67 (45)	74–139 (123)	El-Taher and Abbady [21]
El-Minia 2013	7–188 (50.6)	8–117 (41.3)	47–412 (242.8)	Issa et al. [22]
Nile Delta and Middle 1995	2–96 (18)	5–64 (17)	26–653 (316)	Ibrahiem et al. [24]
Lake Nasser	4–48 (21)	8–50 (23)	16–487 (155)	Ibrahiem et al. [25]
Khartoum, Sudan	17.5 ± 1.8	16.1 ± 0.3	386.8 ± 8.7	Siddeeg et al. [26]
White Nile	17.2 ± 0.5	16.5 ± 0.8	413.1 ± 17.9	Siddeeg et al. [26]
Blue Nile	16.8 ± 0.8	15.0 ± 1.2	423.1 ± 20.4	Siddeeg et al. [26]
Aegean Sea Greece	24–764 (212)	18–66 (43	258–2,464 (1,130)	Travidon et al. [27]
Aegean Sea Turkey	ND	5–63 (24)	220–3,202 (472)	Kemru [28]
Danube River, Serbia	31	26	395	Bikit et al. [29]
Krka River, Croatia	ND	1.9–29.4	18–457	Cukrov and Barišić [30]
Loco Bayon basin	20.6–47.6	24.7–70.5	ND	Yeager et al. [31]
River Tagus, Spain	13–100 (42)	19–145 (63)	48–1,176 (572)	Baeza et al. [32]
Republic of Ireland	10–200 (60)	3–60 (26)	40–800 (350)	McAulay and Morgan [33]
River Tejo, Portugal	42–57	54–76	ND	Carreiro and Sequeira [34]
River Douro, Portugal	42–51	60–85	ND	Carreiro and Sequeira [34]
French Rivers	9–62 (38)	16–55 (38)	120–1,026 (599)	Lambrechts et al. [35]
Apulia, Italy	17–630	16–62	398–649	Battaglia and Bramati [36]
Oslo, Norway	720–1,760	26–50	700–1,400	Stranden and Strand [37]
Belgium	13–43	9–47	170–610	Deworm et al. [38]
Japan	5–130	5–185	75–1,400	Megumi et al. [39]
The Netherlands	ND	22–27	290–700	Köster et al. [40]
China	18–135 (50)	35–228 (90)	281–711 (524)	Ziqiang et al. [41]
Louisiana, USA	64	36	472	Delune et al. [42]
World average	10–50 (25)	7–50 (25)	100–700 (370)	UNSCEAR [43]

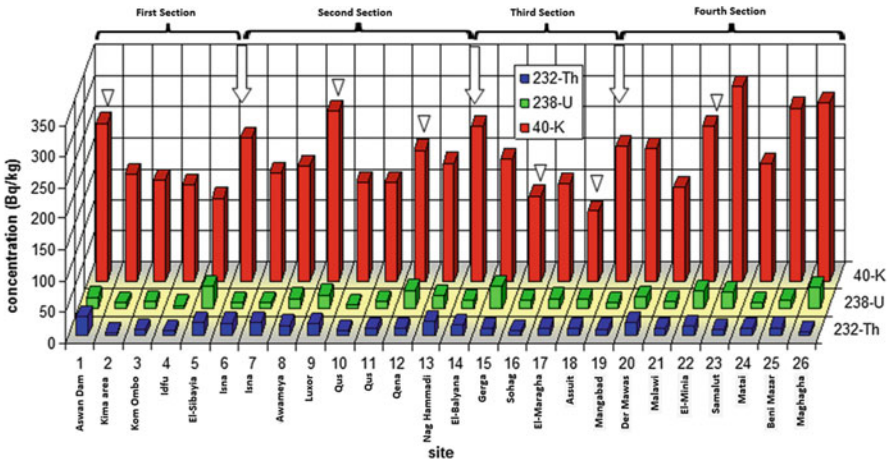

Fig. 6 ^{238}U, ^{232}Th, and ^{40}K concentrations (Bq/kg) in Upper Egypt Nile sediments during 2007. *Big arrows* represent the barrage locations, and the *small arrows* represent the big city locations [20]. The sites under investigation were started from south after the old Aswan Dam (site 1) and sorted to north in Maghagha in El-Minia (site 26). The sites were located as 1–5 in Aswan, 6–13 in Qena, 14–17 in Sohag, 18–19 in Assiut, and 19–26 in El-Minia

6.1 The First Section

The first section is extended from station Isna to Aswan. This section includes the highest and lowest concentration values of ^{238}U and ^{232}Th over all the study area. Relatively high level of ^{238}U concentration has been observed at El-Sibayia. This could be due to the harbor activities of phosphate that transfer through the Nile. Irregular spatial distribution has been observed for ^{238}U and ^{232}Th radioisotopes. Sandy sediments showed the relatively lower ^{238}U and ^{232}Th activity concentration values.

The first section was characterized by wide ranges of ^{238}U and ^{232}Th, from 3.82 ± 1.54 to 34.94 ± 4.01 Bq/kg and from 2.88 ± 1.07 to 30.1 ± 1.83 Bq/kg, respectively. Decline trends of ^{40}K values were observed in the first and third sections as shown in Fig. 6. The first section showed the decline trend of ^{40}K values decreasing from Aswan (253.97 Bq/kg) after the old Aswan Dam to El-Sibayia (133.48 Bq/kg). This could be due to the change of the sedimentation rate with the increased river flow.

6.2 The Second Section

This section was characterized by irregular distribution patterns for ^{238}U, ^{232}Th, and ^{40}K. Relatively low values of the three radioisotopes were observed in the sandy sediments stations such as Awameya and Qus. Relatively high activities have been detected in front of the large cities such as Luxor and Qena. Qena bend of the Nile River plays an important role to increase the levels of ^{238}U and ^{232}Th due to the erosion processes. Significant increase of ^{40}K concentration has been observed next to the Isna barrage.

6.3 The Third Section

Irregular distributions for ^{238}U and ^{232}Th have been observed. Station Gerga has relatively high concentration level of ^{238}U. Declining patterns of ^{40}K concentrations have been observed at the third section from El-Balyana (248.80 Bq/kg) at Sohag Governorate after Nag Hammadi Barrage to Assiut (112.31 Bq/kg). The lowest ^{40}K activity concentration values have been detected in the sandy sediments in front of the two large cities Sohag and Assiut as shown in Fig. 6. The third section was characterized by narrow ranges of ^{238}U and ^{232}Th, from 12.16 ± 2.75 to 34.25 ± 2.68 Bq/kg and from 6.73 ± 1.28 to 16.40 ± 1.69 Bq/kg, respectively.

6.4 The Fourth Section

The fourth section showed a high rate of irregularities for the three isotopes under consideration. The loamy and clay sediments contain ^{238}U concentrations more than the sandy sediments. This is in agreement with the finding of Ibrahiem and his group [25]. Relatively high ^{40}K values have been detected in the loamy sediment stations such as Samalut and Maghagha and in front of the big cities such as Luxor, Qena, and El-Minia as shown in Fig. 6. On the other hand, relatively low ^{40}K values have been detected in the sandy sediments as in front of Sohag and Assiut.

7 Factors Affecting the Distribution of Radioactivity in Sediments Along the Nile River from El-Minia to Aswan

Many factors could be distinguished to play an effective role in the distribution of the detected natural radioisotopes along the study area as mentioned by El-Gamal et al. [20].

Firstly, the presence of the hydraulic structures on the Nile River affects the flow and sedimentation rate of the stream. The locations of these barrages as shown in Fig. 6 such as Aswan (from High Dam and old Aswan Dam), Isna (from Isna barrage), El-Balyana (from Nag Hammadi barrage), and Mangabad (from Assiut barrage) have affected ^{40}K distribution.

The second factor could be the sediment types. The measurements confirmed that the sandy sediments are characterized by low activity concentrations of the detected radioisotopes relative to the other types. Examples of sandy sediment stations are Assiut and Mallawi.

The third factor could be the presence of phosphate as harboring activities such as El-Sibayia, which showed the relatively higher ^{238}U values.

The other factor could be the locations of the big cities. The samples collected from sediments in front of the big cities showed relatively higher activities such as Aswan, Luxor, Qena, and El-Minia. This is could be due to the human activities and its corresponding waste. Moreover, the contamination from the drainage of fertilizers holds radioactive materials; the mineralogical of the sites such as the presence of calcium carbonate and the chemistry of the Nile water could be added as other factors controlling the distribution of the radioisotopes under consideration.

The transportation of black sand through the Nile River and the geographical features of the Nile are also considered as important factors controlling the distribution of the radioactive isotopes under consideration. Radioactive materials could be transported with the flow of the Nile water from the central of Africa and Ethiopia such as the black sand, which is characterized by relatively high radioactivity concentrations [44, 45]. Recently, Lake Nasser and the High Dam have been trapping the majority of these sediments. This indicated that the recent sediments in the Nile River are almost light sediments (not heavy like black sand). The geographical feature of the stream, such as Qena and Nag Hammadi bend, can play an important role to remove the upper light sediment layers and expose the old sediments, which contain black sand.

The detected ranges of ^{238}U and ^{232}Th are in agreement with the other referenced data for the other parts of Nile River [25, 45–48]. The only exception is the black sand locations in both Rashid and Damietta. Agreement has been observed between the detected ranges of ^{232}Th and ^{40}K with the Krka River in Croatia [30]. Table 1 shows the results of ^{226}Ra as ^{238}U, ^{232}Th, and ^{40}K in the area under investigation during years 2006, 2007, 2012, and 2013 with the other values around the Mediterranean Sea area and around the world.

8 Absorbed Dose Rate

Figure 7 shows the absorbed dose rates calculated from ^{238}U, ^{232}Th, and ^{40}K activity concentrations for each location from the Upper Egypt Nile sediments based on the conversion factors given by Yu et al. [49]. El-Gamal and his group detected the range of the total absorbed dose rates during 2007 from 12.71 ± 0.96 to 38.17 ± 1.55 nGy/h with an average of 24.17 ± 7.3 nGy/h [20]. Issa et al. [22] calculated the dose rate of the sediments in the Nile River at Maghagha, Beni Mazar, Mattay, Samalut, Minia, Abu Qurqas, Mallawi, and Deir Mawas. The dose rate values were 49.5, 47.5, 76.0, 43.0, 58.4, 40.5, 36.2, and 61.5 nGy/h, respectively.

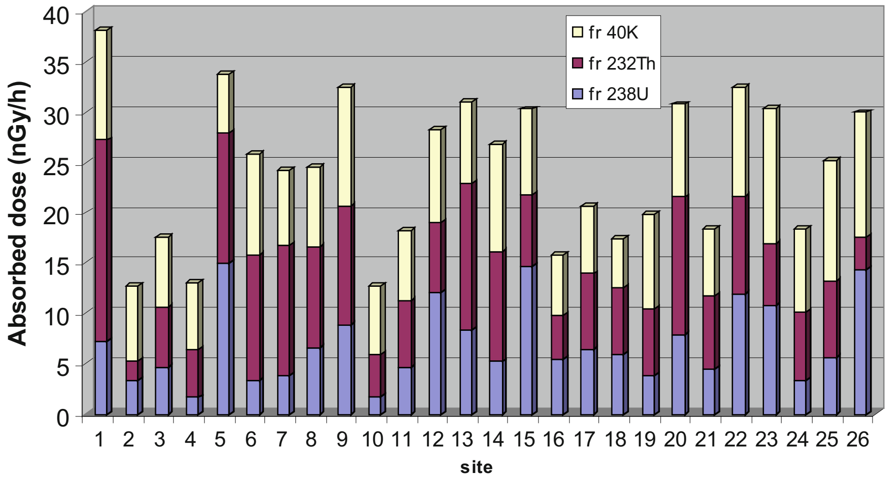

Fig. 7 The contribution of the ^{238}U, ^{232}Th, and ^{40}K fractions for the Upper Egypt Nile sediments absorbed dose calculated values [20]. The sites under investigation were started from south after the old Aswan Dam (site 1) and sorted to north in Maghagha in El-Minia (site 26). The sites were located as 1–5 in Aswan, 6–13 in Qena, 14–17 in Sohag, 18–19 in Assiut, and 19–26 in El-Minia

9 Conclusion

The Egyptian part of the Nile River started from behind the old Aswan Dam to El-Minia was investigated for the distribution of the natural radioactivity in its sediments. The investigation revealed that the natural radioactive elements such as ^{238}U, ^{232}Th, and ^{40}K have been detected with spatial variation along the study area. The area of study was divided into four sections along the Nile River part. The research indicated that the distribution of the radioactivity concentration depends on different factors such as the following:

1. The presence of the hydraulic structures such as dam and barrages on the Nile River affects the flow and sedimentation rate of the stream. These have affected ^{40}K distribution.
2. The presence of black sand through the Nile River. Black sand holding radioactive materials could be transported with the flow of the Nile water from the central of Africa and Ethiopia, which is characterized by relatively high radioactivity concentrations. Recently, Lake Nasser and the High Dam have been trapping the majority of this sand. This indicated that the recent sediments in the Nile River are almost light sediments (not heavy like black sand).
3. The geographical features of the Nile, such as Qena and Nag Hammadi bend, are also considered as important factors controlling the distribution of the radioactive isotopes under consideration. It can play an important role to remove the upper light sediment layers by erosion and expose the old sediments, which contain black sand.

4. The sediment type. The measurements confirmed that the sandy sediments are characterized by low activity concentrations of the detected radioisotopes relative to the other types.
5. The presence of phosphate as harboring activities or from drainage of fertilizers such as El-Sibayia, which showed the relatively higher ^{238}U values.
6. The locations of the big cities. The samples collected from sediments in front of the big cities showed relatively higher activities such as Aswan, Luxor, Qena, and El-Minia.
7. The mineralogical of the sites such as the presence of calcium carbonate.
8. The chemistry of the Nile water could be considered as other factors controlling the distribution of the radioisotopes under consideration.

The detected ranges of the radioisotopes under investigation are in agreement with the other referenced data for the other parts of Nile River. Comparison has been carried out for the presented results with the others around the local and with the international published data.

References

1. NSCEHC (2001) Understanding Radiation in our word. National Safety Council's Environmental Health Center (NSCEHC), Washington DC, 20036 202/293-2270. http://www.nsc.org/ehc.htm
2. Choudhry U (2009) Half life, radioactive waste in India, Toxics link for toxics free world, New Delhi, Chennai, India
3. Lbl (2000) Units of radioactivity and dose, guide to nuclear wall chart. http://www2.lbl.gov/abc/wallchart/chapters/15/2.html
4. USDL (2005) Occupational exposure to ionizing radiation, vol 70. U.S. Department of Labor, Occupational Safety & Health Administration, pp 22828–22835
5. Michel R (2001) Environmental radioactivity measuring methods, proceedings ECORAD 2001, AIX EN PROVENCE. In: Brechingnac F, Howard BJ (eds) Radioactive pollutants – impact on the environment. EDP Science. Les Ulis, France, 3–7 September 2001, pp 27–62
6. Michel R (2000) Quality assurance of nuclear analytical techniques based on Bayesian characteristic limits, PROC. MTAA-10. J Radioanal Chem 245:137–144
7. Weise K, Michel R (1995) Erkennungsgrenzen, Nachweisgrenzen and Vertrauensbereich in der allgemeinen Kernstrahlungs-Spektrometrie. Kerntechnik 60:189–196
8. IAEA (2000) Generic procedures for assessment and response during a radiological emergency. IAEA-TECDOC-1162, International Atomic Energy Agency
9. NCRP (1983) Environmental radioactivity. In: Proceedings of the nineteenth annual meeting of the national council on radiation protection and measurements, National Academy of Sciences, Washington DC, 6–7 April 1983
10. NCRP (1976) Environmental radiation measurements, recommendations of the National Council on Radiation Protection and Measurements NCRP Report No. 50
11. Harley NH, Pasternak BS (1979) Potential carcinogenic effects of actinides in the environment. Health Phys 37:291
12. Eisenbud M (1982) Conclusions derived from the 1975 conference on area of high natural radioactivity; Natural radiation environment. In: Proceeding of special symposium on natural radiation environment, Wiley Eastern Limited, India, 19–23 January 1981

13. El-Naggar AM (1990) Environmental radioactivity; sources and effects on man. In: El-Raey M (ed) Regional symposium environmental studies (UNARC), Alexandria University
14. Eggebert WS, Pfennig G, Münzel H (1974) Chart of the nuclides. Gesellschaft für Kernforschung mbH, Karlsruhe
15. Ammar AA, Wassef SN, Meleik ML, Fouad KM, Dabbour GA (1983) Remote surface and laboratory detection of radioactive minerals of Rosetta black sand beach deposits. Egypt Int J Remote Sens 4(4):739–754
16. El-Saharty AA (2013) Radioactive survey of coastal water and sediments across Alexandria and Rashid coasts. Egypt J Aquat Res 39:21–30
17. Dabbour GA (1994) The Egyptian placer deposits- a potential source for nuclear raw materials. In: Second Arab conference on the peaceful uses of atomic energy, Cairo, 5–9 November 1994
18. El-Gamal AA (2004) Assessment of radioactivity along the Mediterranean coast of Egypt. Ph. D. Thesis, Institute of Graduate Studies and Research, Alexandria University
19. White EI (2012) Consideration of radiation in hazardous waste produced from horizontal hydrofracking. Grassroots Environmental Education. http://www.grassrootsinfo.org/pdf/whitereport.pdf
20. El-Gamal A, Nasr S, Eltaher A (2007) Study of the spatial distribution of natural radioactivity in the upper Egypt Nile sediments. Radiat Meas 42(3):457–465
21. El-Taher A, Abbady AGE (2012) Natural radioactivity levels and associated radiation hazards in Nile River sediments from Aswan to El-Minia, Upper Egypt. Indian J Pure Appl Phys 50:224–230
22. Issa S, Uosif M, Elsaman R (2013) Gamma radioactivity measurements in Nile River sediment samples. Turkish J Eng Environ Sci 37:109–122
23. Uosif MAM (2007) Gamma-ray spectroscopic analysis of selected samples from the Nile river sediments in Upper Egypt. Radiat Prot Dosimetry 123(2):215–220. doi:10.1093/rpd/ncl103
24. Ibrahiem NM, Shawky SM, Amer HA (1995) Radioactivity levels in lake Nasser sediments. Appl Radial Isot 46(5):297–299
25. Ibrahiem NM, Abd El Ghani AH, Shawky SM, Ashraf EM, Farouk MA (1993) Measurement of radioactivity levels in soil in the Nile delta & middle Egypt. Health Phys 64(6):620–627
26. Siddeeg SMB, Alfatih AKS, Osman AA, Salih I, Khalid MAA (2009) Distribution of ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs in River Nile sediments, Khartoum, Sudan. Phil Nat 1(1):109–120
27. Travidon G, Flouro H, Angelopoulos A, Sakellioou L (1996) Environmental study of the radioactivity of the spas in the Island of Ikaria Greece. Radiat Prot Dosimetry 63:63–67
28. Kemru MN (1997) Possible uranium rich areas in the Aegean region of Turkey. Appl Radiat Isot 48:295–299
29. Bikit I, Slivka J, Vesković M, Varga E, Žikić-Todorović N, Mrđa D, Forkapić S (2006) Measurement of Danube sediment radioactivity in Serbia and Montenegro using gamma ray spectrometry. Radiat Meas 41:477–481
30. Cukrov N, Barišić D (2006) Spatial distribution of ^{40}K and ^{232}Th in recent sediments of the Krka River Estuary. Croatia Chem Acta 79(1):115–118
31. Yeager KM, Santschi PH, Philips JD, Herbert BE (2002) Sources of alluvium in a coastal plain stream based on radionuclide signatures from the ^{238}U and ^{232}Th decay series. Water Resour Res 38(11):1242, 24-1-24-11
32. Baeza A, del Rio M, Miró C, Paniagua JM (1992) Natural radioactivity in soils of the province of Cáceres (Spain). Radiat Prot Dosimetry 45(1–4):261–263
33. McAulay IR, Morgan D (1988) Natural radioactivity in soil in the Republic of Ireland. Radiat Prot Dosimetry 24(1–4):47–49
34. Carreiro MCV, Sequeira MMA (1988) ^{226}Ra and ^{228}Ac in a freshwater ecosystem. Radiat Prot Dosimetry 24(1–4):133–137
35. Lambrechts A, Foulquier L, Garnier-Laplace J (1992) Natural radioactivity in the aquatic components of the main French rivers. Radiat Prot Dosimetry 45(1–4):253–256
36. Battaglia A, Bramati L (1988) Environmental radiation survey around a coal-fired power plant site. Radiat Prot Dosimetry 24(1–4):407–410

37. Stranden E, Strand T (1988) Radon in an Alum Shale Rich Norwegian Area. Radiat Prot Dosimetry 24(1–4):367–370
38. Deworm JP, Slegers W, Gillard J, Flemal JM, Culst JP (1988) Survey of the natural radiation of Belgium territory as determined by different methods. Radiat Prot Dosimetry 24 (1–4):347–351
39. Megumi K, Oka T, Doi M, Kimura S, Tsujimoto T, Ishiyama T, Katsurayama K (1988) Relationships between the concentrations of natural radionuclides and the mineral composition of the surface soil. Radiat Prot Dosimetry 24(1–4):69–72
40. Köster HW, Keen A, Pennders RMJ, Bannink DW, de Winkel JH (1988) Linear regression models for the natural radioactivity (^{238}U, ^{232}Th and ^{40}K) in Dutch soils: a key to anomalies. Radiat Prot Dosimetry 24(1–4):63–68
41. Ziqiang P, Yin Y, Mingqiang G (1988) Natural radiation and radioactivity in China. Radiat Prot Dosimetry 24(1–4):29–38
42. Delune RD, Jones GL, Smith CJ (1986) Radionuclide concentrations in Louisiana soils and sediments. Health Phys 51:239–244
43. UNSCEAR (2000) Exposures from natural radiation sources. United Nations Scientific Committee on Effects of Atomic Radiation, UNSCEAR Report, New York
44. El-Gamal A, Saleh I, Nas S, Naim M (2006) Radiological assessment of the Egyptian Mediterranean coast. In: Isotopes in environmental studies, Aquatic Forum 2004, Proceedings of an international conference held in Monaco, 25–29 October 2004 organized by IAEA, IAEA-CN-118/31P, pp 290–291
45. El-Tahawy MS, El-Moafy W, Higgy R (2001) Radiological investigation of the East Nile estuary to the Mediterranean Sea. In: Ocean/atmosphere biogeochemical coupling symposium, organized by the International Association for the Physical Sciences of the Oceans (IAPSO), IM01-15
46. Ismail SS, Unfried E, Grass F (1993) Distribution of ^{137}Cs and ^{228}Ra in the sediments of Aswan High Dam Lake. J Radioanal Nucl Chem 186(2):143–155
47. Khater AE, Ebaid YY, El-Mongy SA (2005) Distribution pattern of natural radionuclides in Lake Nasser bottom sediments. Int Congr Ser 1276:405–406
48. Saleh I, El-Gamal A, Nasr S, Naim M (2006) Spatial and temporal variations of uranium and thorium series along the Egyptian Mediterranean coast. In: Isotopes in environmental studies, Aquatic Forum 2004, Proceedings of an international conference held in Monaco, 25–-29 October 2004 organized by IAEA, IAEA-CN-118/113P, pp 452–454
49. Yu KN, Guan ZJ, Stocks MJ, Young EC (1992) The assessment of natural radiation dose in Egyptian population from radio contaminated food after Chernobyl accident. In: El-Raey M (ed) Regional symposium environmental studies (UNAR) Alexandria

Assessment of Water Quality and Bed Sediments of the Nile River from Aswan to Assiut, Egypt

Abbas Sharaky, Talaat Salem, and Ayman Abdel Aal

Abstract The Nile River water quality and its bed sediments were studied for two successive years (2011 and 2012) at ten sites along the Nile River from Aswan to Assiut during low and high flow conditions. Physical and chemical water quality parameters were measured according to the standard methods, such as temperature, turbidity, water electrical conductivity (EC), total suspended solids (TSS) and total dissolved solids (TDS), pH value, dissolved oxygen (DO), nutrients, biological oxygen demand (BOD), chemical oxygen demand (COD), total organic carbon (TOC), major anions and cations, hardness, heavy metals, and fecal coliform bacteria. The water quality along the Nile in the study area is classified as medium to good quality. It changes from low to high flow and from one place to another according to human activities. The water pollution was higher during the low flow than the high flow except for the nutrients due to low agricultural activities during low flow periods. However, in general, the Nile River water quality was suitable for human consumption and other domestic uses according to the WHO standards. The bed-sediment samples were used for grain size analysis, pH measurements, organic matter content, phosphates, nitrates, and heavy metals (lead, cadmium, nickel, zinc, iron, manganese, copper, and barium). This chapter inspects the water quality of the Nile River and pollution of its bed sediments in Egypt.

Keywords Bed sediments, High flow, Low flow, Nile River, Pollution, Water quality

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A. Sharaky (✉), T. Salem, and A.A. Aal
Department of Natural Resources, Institute of African Research and Studies, Cairo University, P.O. Box 12613, Giza, Egypt
e-mail: sharaky@geologist.com

A.M. Negm (ed.), *The Nile River*,
Hdb Env Chem (2017) 56: 207–238, DOI 10.1007/698_2016_118,

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1 Introduction

The Nile River is the longest river in the world with a length of 6,695 km [1], running through 11 countries that are home to 494.4 million people in mid. 2016 [2]. The Nile basin itself is home to more than 260 million people or around 22% of the population of the African continent. The Nile River provides Egypt about 97% of water needs, 15% of electricity, and 95% of rich soil. Therefore, the Nile River is the vital source of water for Egypt. Throughout the known Egyptian history, the Nile had dominating influences on the economy, culture, public health, social life, and political aspects. However, any changes in the Nile water quantity, quality, and distribution will have serious ecological impacts.

Protecting and monitoring the river and its tributaries are the major concerns for many Egyptian authorities. Water quality is increasingly important as Egypt tries to meet a growing portion of its future water needs through reuse of water. Increasing the human's standards of life requires progress in industrialization, transportation tools, and agriculture, which may affect the environmental air, water, and soil.

The Nile with its two branches (Damietta and Rashid) has been subjected to different sources of pollution, which affect its physical, chemical, and biological characteristics [3]. These sources include industrial, agricultural, and municipal wastes. Industrial wastewater is considered as the most important pollutant for the environment especially for drinking water.

The quantities and quality of wastewater from agricultural lands are highly variable. The most important pollutants found in runoff from agricultural areas are sediments, animal wastes, plant nutrients, crop residues, inorganic salts, minerals, chemical fertilizers, and pesticides in addition to domestic wastes [4]. More fertilizers and chemicals have been used to increase agricultural production, some of which are leached into the Nile water.

The municipal wastewater, which pollutes water through drains to the Nile, contains oil, grease, scum, pathogenic bacteria, viruses, salts, heavy metals, and refractory organic compounds. Environmental pollution, mainly of water sources, has become of public interest. Natural events and anthropogenic influences can affect the aquatic environment in many ways; addition of synthetic substances changes the physical or chemical nature of the water that changes the biological communities [5].

River basins generally constitute areas with a high population density due to the favorable availability of fertile soils and water for irrigation. Rivers play a major role in assimilating or carrying off industrial and municipal wastewater, manure discharges, and runoff from agricultural fields, roadways, and streets, which are responsible for river pollution [6]. The Nile water quality has been studied heavily after the construction of the Aswan High Dam (AHD). The studies include Abdel-Aal et al., Mahrous, Abdel-Satar, Abdel-Rehim et al., Abo El-Hassan et al., Shehata and Badr, Yousry et al., and Abtew and Melesse [7–14].

This chapter aims to investigate the physicochemical characteristics of the Nile water from Aswan to Assiut to detect pollution that may impact on human health and the biological quality elements and affect overall ecological status. They include temperature, turbidity, water electrical conductivity (EC), total suspended solids (TSS) and total dissolved solids (TDS), pH value, dissolved oxygen (DO), nutrients, biological oxygen demand (BOD), chemical oxygen demand (COD), total organic carbon (TOC), major anions and cations, hardness, heavy metals, and fecal coliform bacteria.

River bottom sediments are basic components of the fluvial environment. The Nile River sediments are derived mainly from the Ethiopian volcanic highlands including minor granite, schist, sandstone, and carbonate rocks. They constitute a major source of persistent bioaccumulative toxic chemicals which may pose threats to ecological and human health. The pollution of river bottom recently deposited sediments may indicate the water quality because they act as a sink for metal contaminants. The Nile bottom sediments between Aswan and Isna show that they have been polluted by Cd, Pb, and U [15].

The geology and origin of the Nile Valley in Egypt were studied by several researchers including El-Kammar et al., Shukri, El-Kammar et al., Said, Abdel-Fattah et al., Garzanti et al., Issa et al., Arafa et al., and Woodward et al. [15–23]. The main targets of studying the Nile bottom recent sediments were investigation of type and availability of metals in sediments along the Nile River in study, which may reflect the Nile water quality.

2 Background

2.1 Water Resources in Egypt

The Nile water supplies about 97% of the renewable freshwater in Egypt. It is represented by 55.5 km^3 according to the 1959 agreement with Sudan. The Ethiopian Highlands provide the Nile about 85% of its water through Blue Nile, Sobat, and Atbara rivers [24]. The Nile water in the study area is controlled by the AHD

Table 1 Contribution of the main Nile sources [25]

Source	River	Water share in km^3 at Aswan	%
Ethiopian Highlands	Blue Nile	50	60
	Atbara (Tekeze)	10	12
	Baro–Akobo–Sobat	11	13
Equatorial Plateau	Lake Victoria – Bahr el Jebel	13	15
Total		84	100

built in 1970, the Old Aswan Dam (1902), Esna (1908), Nag Hammadi (1930), and Assiut (1902, renewed in 2016) dams.

2.2 *Sources of the River Nile*

The River Nile comes from two main sources: Ethiopian sources where 85% of the Nile water comes from and the Equatorial Plateau of East Africa (see Table 1).

2.2.1 Ethiopian Sources

The Ethiopian sources share the Nile through three rivers that originate from their highlands: (a) The Blue Nile (Abay) River, (b) Atbara (Tekeze) River, and (c) Baro–Akobo–Sobat River.

The Blue Nile

The Blue Nile flows about 1,400 km from Lake Tana to Khartoum, where the Blue Nile and White Nile join to form the main Nile (see Fig. 1). It provides the Nile by 50 km^3 annually (about 60%). It extends for about 850 km from Lake Tana to the Sudano-Ethiopian border, with a fall of 1,300 m; the grades are steeper in the plateau region, and flatter along the low lands [1]. More than 95% of the transported sediments (clay) carried by the Nile originates in Ethiopia, from the Blue Nile, Atbara, and Sobat, and small tributaries [26].

The Baro–Akobo–Sobat River

The Baro–Akobo–Sobat River includes the three main tributaries: the Baro and Akobo rivers from the Ethiopian Highlands and the Pibor River from southern Sudan and northern Uganda. Most of the runoff comes from the Ethiopian mountains.

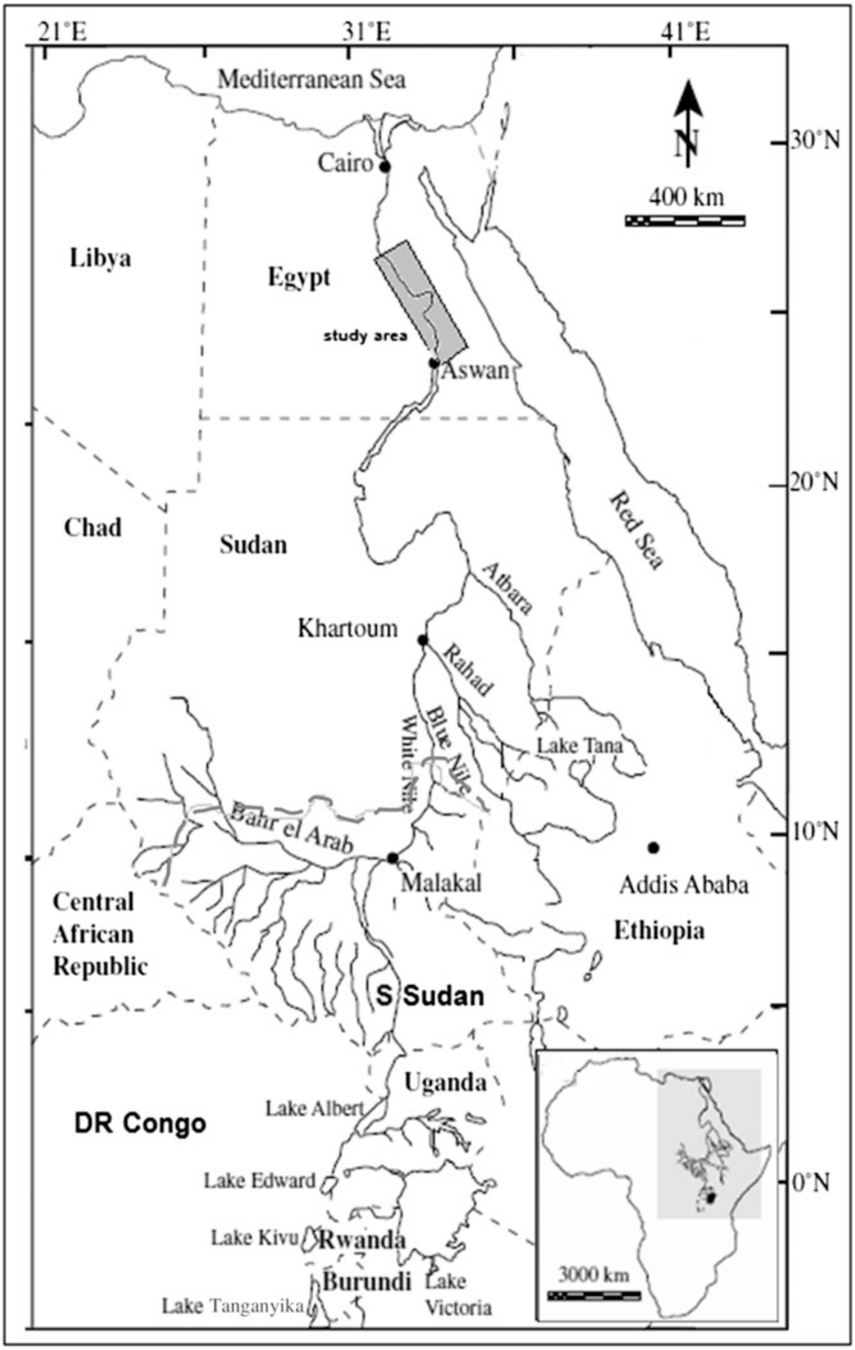

Fig. 1 Nile River basin and the study area

The Atbara River

The Atbara River is the last major river that joins the Nile River at about 320 km north Khartoum. The Nile River experiences massive fluctuations throughout the year, with 80% of the annual discharge occurring between August and October [24].

2.2.2 Equatorial Sources

The White Nile

The White Nile originates at the confluence of Bahr el Jebel River and Baro–Akobo–Sobat River at Malakal, South Sudan (see Fig. 1). The Bahr el Jebel extends from the mountains of Burundi and Rwanda, the Equatorial Lakes. A number of tributaries from Burundi and Rwanda eventually flow into the Kagera River, over Rusumu Falls and into Lake Victoria. The Victoria Nile flows out from the northern end of Lake Victoria over into Lake Kyoga, Uganda where the Lower Victoria Nile flows westwards to join Albert Nile, forming Bahr el Jebel at the border of Uganda at Nimule. It loses half of its water in the Sudd swamp region, Southern Sudan [24].

Victoria Lake

Lake Victoria is the largest of the Nile Equatorial Lakes with a surface area of about 66,700 km^2 that occupies a large proportion of the entire subbasin. Three countries Kenya (6%), Tanzania (51%), and Uganda (43%) share the lake shoreline, and six countries share the basin: Burundi, DRC, Kenya, Rwanda, Tanzania, and Uganda.

Lake Victoria, 1,134 m above sea level, is by far the largest lake (66,700 km^2) in Africa, and the second largest freshwater lake in the world. Annual water inflow into Lake Victoria through the main tributaries is about 18 km^3. It also receives about 100 km^3/year from direct rainfall. Therefore, it is one of the most fresh water in Africa with low TDS. Similar to most of the African continents, the annual evaporation rate is about 80%.

The net annual outflow from the lake through the Upper Victoria Nile is 23.5 km^3 [24]. The concentration of the metal content (salinity) of the Nile River increases with the distance from the AHD to the north due to the washing of surface rocks and the human activities. The average salinity of the Nile in Egypt is much greater than that of Victoria.

3 Material and Methods

The study area is located along the Nile River from Aswan to Assiut, extending for about 500 km. The site samples were chosen taking into considerations the low and high flow conditions. Moreover, one site downstream the dam was chosen as a reference point (9.9 km from High Dam). The sampling of the Nile water was carried out twice during low flow (LF) and high flow (HF) conditions in February and August of two successive years (2011 and 2012) at ten sites (see Fig. 2) along the Nile River from Aswan to Assiut (see Table 2). The collected samples were used to measure the physiochemical characteristics of the Nile water and bed sediments.

The different chemical analyses were carried out according to the standard methods for testing of water and wastewater, proposed by the American Public Health Association [27].

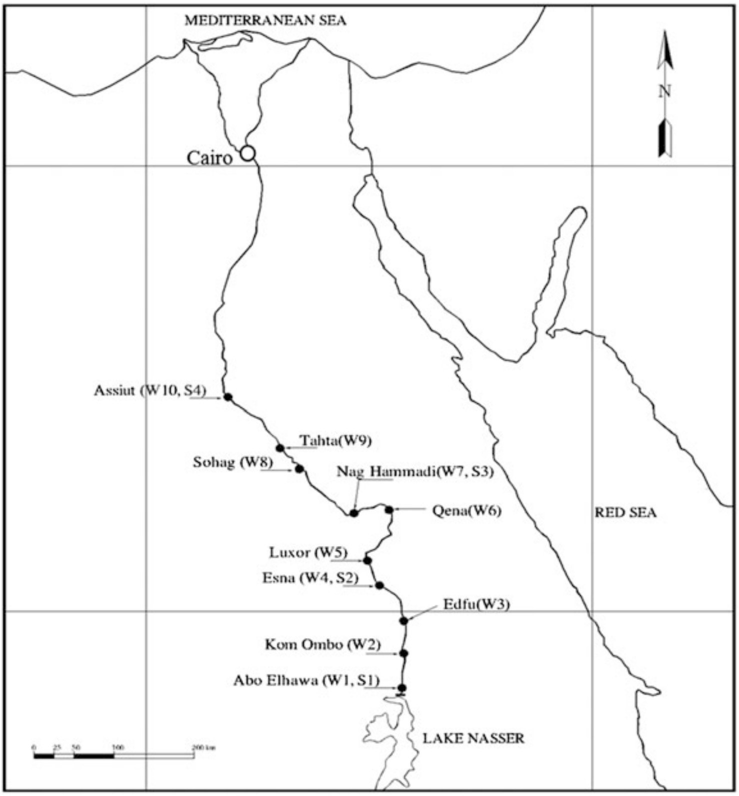

Fig. 2 Sampling sites along the Nile River (*W* water, *S* sediment samples)

Table 2 Distance from the Aswan High Dam (AHD, km), latitudes, and depth of the studied samples

Site names	Distance from AHD (km)	Coordinates	Mean depth (m)
Abo Elhawa (Aswan)	9.9	32° 53′ 96″ E 24° 06′ 99″ N	5.5
Kom Ombo	53.3	32° 54′ 97″ E 24° 27′ 74″ N	4.3
Edfu	116.2	32° 52′ 64″ E 24° 57′ 82″ N	8.4
Esna Barrage	168.0	32° 33′ 72″ E 25° 17′ 59″ N	7.5
Luxor	222.0	32° 37′ 70″ E 25° 41′ 22″ N	5.6
Qena	277.0	32° 43′ 48″ E 26° 08′ 47″ N	5.5
Nag Hammadi Barrage	331.0	32° 29′ 59″ E 26° 07′ 07″ N	6.5
Sohag	445.6	31° 42′ 24″ E 26° 32′ 63″ N	4.9
Tahta	489.0	31° 31′ 17″ E 26° 49′ 81″ N	4.5
Assiut	545.0	31° 11′ 67″ E 27° 11′ 52″ N	6.0

4 Results and Discussion

4.1 Water Quality

Various physicochemical and bacteriological parameters like temperature, pH, DO, turbidity, BOD, nitrate, phosphate, TDS, and fecal coliform were determined by following the standard methods [27]. All the reagents used for the analysis were analytical reagent grade. The quality assurance and quality procedure were also used as described in APHA.

4.1.1 Temperature

The temperature is a key parameter, which influences all physical, chemical, and biological processes in aquatic environments. In general, as water temperature increases, the rate of chemical reactions increases. The temperature affects the rate of growth and life cycles of most aquatic organisms. It is known to influence the pH, alkalinity, and DO concentration in the water. Water temperatures along the Nile River showed a highly significant difference between high and low flow (temporal variation $p < 0.05$) and have the following range: During high flow, the water temperature ranged from 25.25°C to 28.75°C (see Fig. 3). In low flow, it

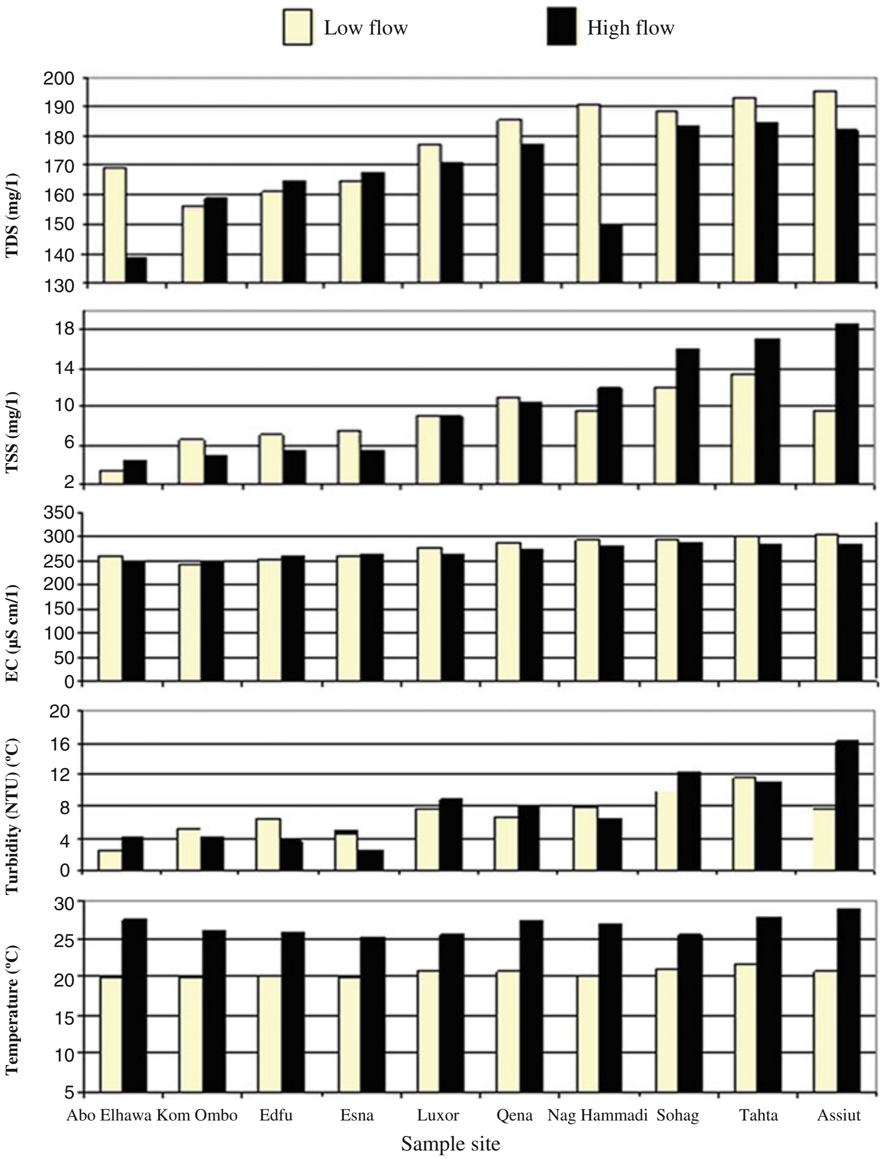

Fig. 3 Average values of the physiochemical parameters along the Nile from Aswan to Assiut during low and high flow conditions (2011–2012)

showed the lowest temperatures that ranged from 19.90°C to 20.80°C. It is worth to mention that high water temperature values in high flow are related to the rise in air temperature (incident solar radiation). In addition, the solid particles floating on the water absorbed heat more rapidly and then radiated the heat again to the surrounding water medium [28].

4.1.2 Turbidity

The turbidity is derived from silt, clay, and sand particles, while organic turbidity is composed of planktonic organisms and detritus. In low flow, turbidity values varied from 2.65 NTU at Abo Elhawa site to 11.56 NTU at Tahta site (see Fig. 3). In high flow, the turbidity values are mainly higher than those of low flow, which ranged from 2.69 NTU at Esna to 16.20 NTU at Assiut. The increasing of turbidity values is referred to increasing of suspended materials will reduce light penetration and restrict plant growth and hence food resources and habitat for organisms. Results of *t*-test showed that there was a significant difference ($p < 0.05$) between different flows. The results of turbidity values exceed the permissible limits of law and the guidelines of WHO [29] (5 NTU) for drinking water in most locations except Abo Elhawa. The Nile water is valid for drinking after treatment and for irrigation.

4.1.3 Electrical Conductivity (EC)

The electric conductivity of the Nile River water in the study area ranges from 243 (at Kom Ombo) to 305 μS/cm (at Assiut) during low flow period; however, it ranged from 246 (at Abo Elhawa) to 287 μS/cm (at Sohag) in high flow condition (see Fig. 3). The EC increases from Aswan to Assiut due to increasing of the dissolved ions resulted from the human activities especially agriculture.

4.1.4 Total Suspended Solids

The suspended particles are the main source of turbidity in water, which always interfere with the penetration of light. In this study, the suspended solid concentrations in waters along the River Nile show an increase during high flow than low flow. They also increase from Aswan to Assiut as in the EC (see Fig. 3).

4.1.5 Total Dissolved Solids

The TDS concentration in water samples collected along the Nile River ranged between 167.9 and 178.3 mg/l (see Fig. 3). The TDS values increase with the distance from the AHD to the north in both low and high flow conditions due to leaching and agricultural discharge.

In low flow, TDS concentration varied from 155.5 mg/l at Kom Ombo to 195.5 mg/l at Assiut. In high flow, its values ranged from 138.5 mg/l at Abo Elhawa to 184.5 mg/l at Tahta. The TDS concentration at Abo Elhawa (Aswan) at high flow (170 mg/l) is slightly higher than the average of the AHD reservoir (150 mg/l).

In irrigation water, the salinity hazard is related to the high values of TDS. The total dissolved salts along the Nile River were less than 450 mg/l and there was no restriction on using it for some susceptible crops [30].

Results of *t*-test showed that there was a significant difference ($p < 0.05$) between different flows along the Nile River. Generally, all TDS values along the Nile River were found within the permissible limits of law 48/1982 (500 mg/l).

Nile Water Quality Compared to Some Major Rivers and Lakes

The Nile water receives fluxes of elements through natural processes by weathering of bed rocks. Ethiopian Highlands are enriched in basic volcanic rock, mainly basalts that are easily eroded by rainfall. The basalts contain weak olivine ($(Mg, Fe)_2SiO_4$) and pyroxene ($(Mg, Fe, Ca, Al)_2(Si, Al)_2O_6$) minerals that are enriched in some elements such as Na, Li, Fe, Mn, and Mg in addition to Si. These elements transport with water to increase the TDS of the Nile, in contrast to the White Nile water that flows from the equatorial highlands enriched mainly in granites. The TDS of Lake Tana, source of the Blue Nile, varies from 50 to 138 mg/l with an average of 103 mg/l [31]. It increases with the distance towards Sudan.

The Nile River is higher in concentration of total major ions (TDS) relative to the major rivers and lakes of the world (see Fig. 4) due to the long distance of the Nile flow to the Mediterranean Sea, and the abundance of the basaltic source rock in

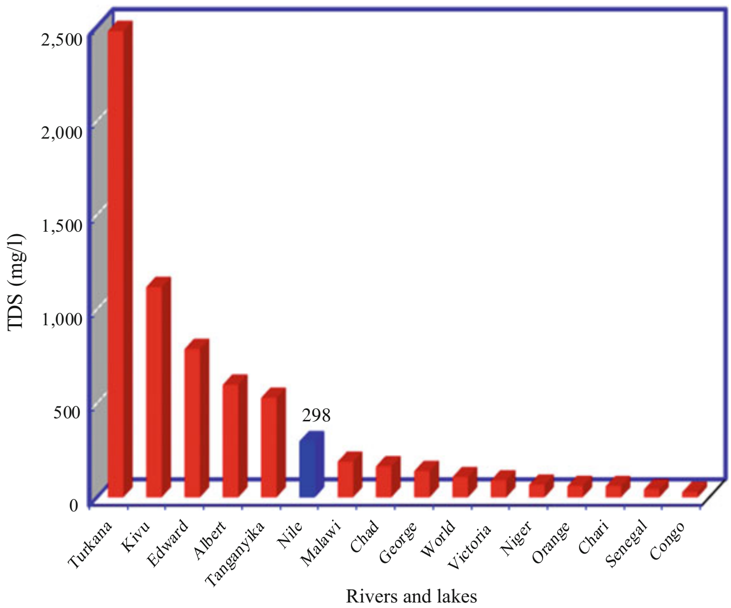

Fig. 4 Average total dissolved solids (TDS) of the Nile in comparison with major rivers and lakes (compiled from different sources)

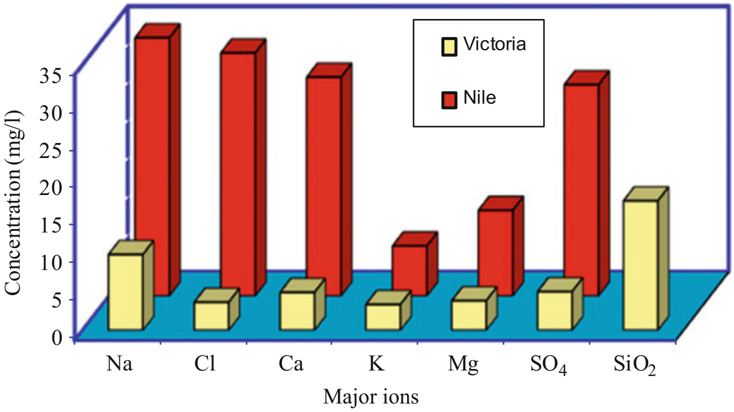

Fig. 5 Average chemical composition of the Nile River and Lake Victoria (data compiled from Shahin, Chapman, and Allem and Samman [24, 32, 33])

Ethiopian Highlands. The major ions represented by TDS have been also significantly increased by anthropogenic contaminations. The average salinity of the Nile River at Cairo ranges from 175 to 680 mg/l with an average of 261 mg/l [12].

Lake Victoria, 1,134 m above sea level, is by far the largest lake (66,700 km^2) in Africa [1], and the second largest freshwater lake in the world.

Three countries Kenya (6%), Tanzania (51%), and Uganda (43%) share the lake shoreline, and six countries share the basin: Burundi, DR Congo, Kenya, Rwanda, Tanzania, and Uganda. Annual water inflow into Lake Victoria through the main tributaries is about 18 km^3.

Lake Victoria receives about 100 km^3/year from direct rainfall [32]. Therefore, it is one of the most fresh water in Africa in terms of TDS content. Similar to most of the African continents, the annual evaporation rate is about 80%. The net annual outflow from the lake through the Upper Victoria Nile is 23.5 km^3 [24]. The concentration of the major cations of the Nile River increases with the distance from the AHD to the north due to the washing of surface rocks and the human activities. The average TDS of the Nile in Egypt (298 mg/l) is much greater than that of Victoria (45 mg/l, see Fig. 5).

4.1.6 The pH Values

The pH of the Nile River water varied in different flow conditions along the ten sites. During low flow, the pH values ranged from 8.29 at the Kom Ombo site to 8.50 at Sohag (see Fig. 6). In high flow, the pH value ranged between 7.94 at Kom Ombo and 8.48 at Sohag. The lowering of pH value of the Nile River that appear from drainage water may be attributed to greater input of organic matter where the high organic matter led to decrease in pH values [29]. The increase of pH values at the Nile water is a result of photosynthesis and plant or phytoplankton growth

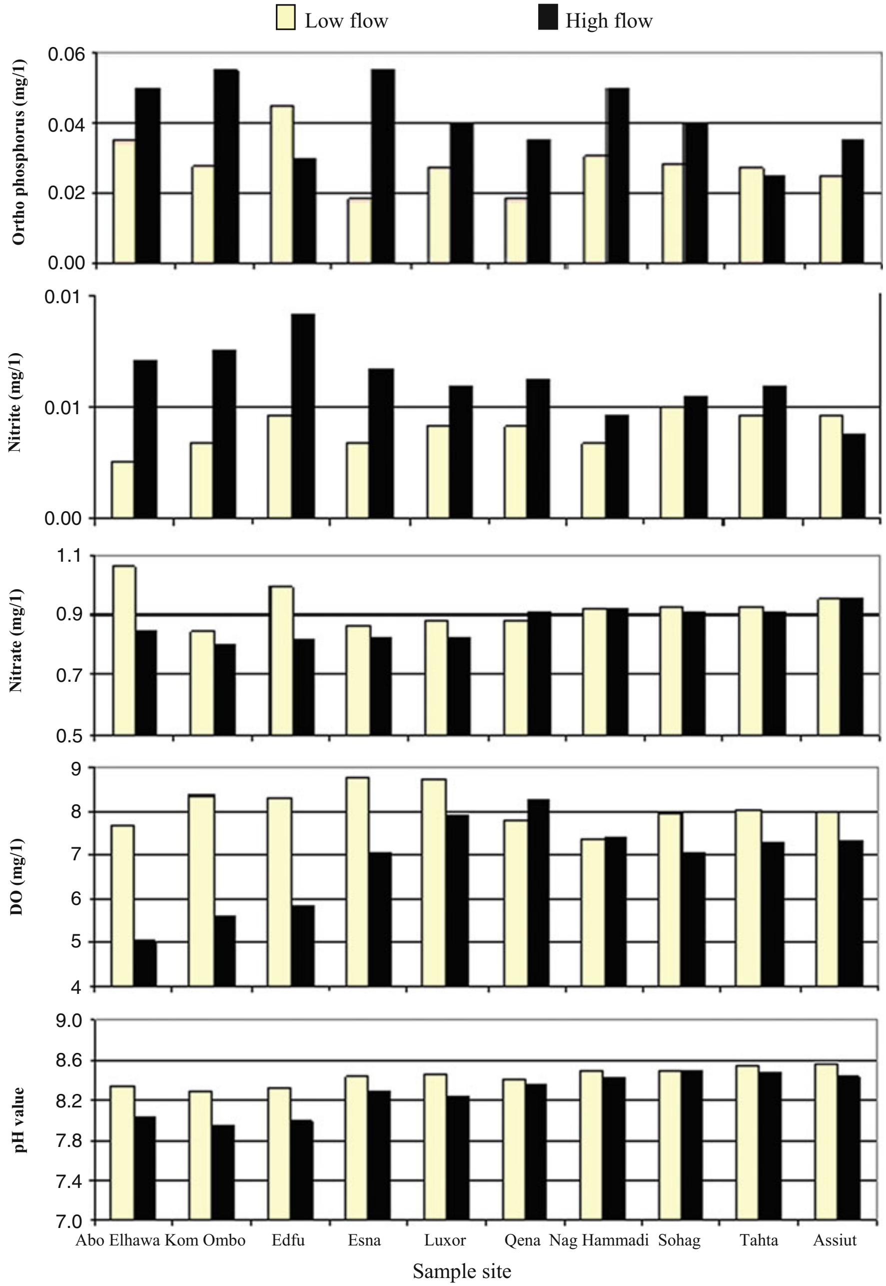

Fig. 6 Average values of the chemical parameters along the Nile from Aswan to Assiut during low and high flow conditions (2011–2012)

[34, 35]. In general, unpolluted streams normally show a near neutral or slightly alkaline pH. Finally, the Nile River has pH values within the permissible limits of law 48/1982 (7.94–8.50) and are not harmful for aquatic life and irrigation, where the pH of most natural water ranges between 6 and 8.5 [36]. The normal pH for irrigation water is from 6.5 to 8.4 [37].

Dissolved oxygen is essential for aquatic life specially fish and other aquatic species require oxygen. Dissolved oxygen allows aerobic bacteria to degrade a wide variety of organic matter and oxidize inorganic salts. The concentration of DO along the Nile was higher during low flow than during high flow (see Fig. 6). It ranges between 7.35 and 8.80 mg/l during low flow, and between 5.02 and 8.30 mg/l during high flow. The highest DO value (8.80 mg/l) was recorded in the surface water of upstream Esna Barrage during low flow while the lowest was at Abo Elhawa during high flow. The decrease of DO may be attributed to the consumption of DO by respiration of phytoplankton, aquatic plants, and fish, and decay of the aerobic bacteria [38].

4.1.7 Dissolved Oxygen (DO)

Dissolved oxygen value was greatly affected by pollution load where the lowest DO is recorded at sites in high flow, and the excessive effluent discharge of pollution with high load of organic matter into the Nile stream leads to deoxygenating of water. The highest value of DO recorded at sites in low flow may attribute to the high rate of biosynthesis of oxygen. Waste discharges that are characterized by high inorganic matter and nutrients can lead to decreases in DO concentrations as a result of the increased microbial activity (respiration) occurring during the degradation of the organic matter [39]. The DO at the Nile water was higher during low flow than during high flow (see Fig. 6).

4.1.8 Nutrients

The increase of nutrients, ammonia and phosphates, is generally indicative of diffuse pollution (agriculture, forestry, and septic tanks) and point source pollution (e.g., municipal or industrial wastewater treatment plants). Nutrients are considered as essential elements needed to the growth and reproduction of plants and animals. Nitrogen compounds occur as nitrate (NO_3), nitrite (NO_2), ammonia (NH_3), and organic nitrogen.

Ammonia was measured in all water samples collected from all sites during both flow conditions. Its concentrations were recorded below the detection limit of <0.01 mg/l.

Natural sources of nitrate in surface waters are the interaction with igneous rocks, land drainage, plant and animal debris [30]. Determination of nitrate and nitrite in rivers gives a general indication of the nutrient status and level of organic pollution. The nitrate content was slightly higher during low than high flow (see Fig. 6).

The nitrate levels were quite low, varying from 0.85 mg/l at Kom Ombo to 1.07 mg/l at Abo Elhawa site in low flow condition (see Fig. 3). Thus, there was no indication of nitrate pollution in the Nile River in high flow condition, and the nitrate concentration varied from 0.82 mg/l at Edfu site to 0.95 mg/l at Assiut site.

The decrease of nitrate along the Nile River may be related to the presence of denitrifying bacteria or related to biological uptake. In the study area along the Nile River, the nitrate concentrations were found to be within the permissible limits of law 48/1982 (not exceed 45 mg/l). As the World Health Organization [40] recommended maximum limit for drinking water is 10 mg/l NO_3-N, waters with higher nitrate concentrations represent a significant health risk. Comparing the results of nitrate of the Nile River water with FAO guidelines (5 mg/l N), we found that there is no restriction on its use for sensitive crops.

Results of *t*-test showed that there is no significant difference ($p > 0.05$) between different conditions. The nitrite ion is rapidly oxidized to nitrate. Nitrite concentration values range from <0.003–0.01 mg/l (see Fig. 6).

4.1.9 Orthophosphate

Orthophosphate is present in natural waters as soluble phosphates. In low flow, the concentration of available phosphates varied from 0.02 mg/l at Esna and Edfu sites to 0.04 mg/l at Abo Elhawa. In high flow, its values ranged from 0.03 mg/l at Edfu and Tahta sites to 0.06 mg/l at Kom Ombo and Esna sites (see Fig. 6). Agricultural runoff containing phosphate fertilizer and wastewater containing detergents tend to increase phosphate pollution in the Nile River. Klein and Morel [40, 41] concluded that the decrease and depletion of phosphate may be related to its adsorption on hydrous FeO, Fe_2O_3, or Al_2O_3, and its consumption by algae, bacteria, or other aquatic plants. Phosphate concentrations along the Nile River showed a lightly significant difference between different conditions ($p < 0.05$).

4.1.10 Total Phosphorus

Phosphorus is an essential nutrient element for living organisms and exists in water bodies as both dissolved and particulate forms. Natural sources of phosphorus are mainly derived from weathering processes of phosphorus bearing rocks and the decomposition of organic matter [29]. During high flow, total phosphorus value ranged between 0.06 and 0.10 mg/l, while it ranged between 0.06 and 0.10 mg/l during low flow (see Fig. 7).

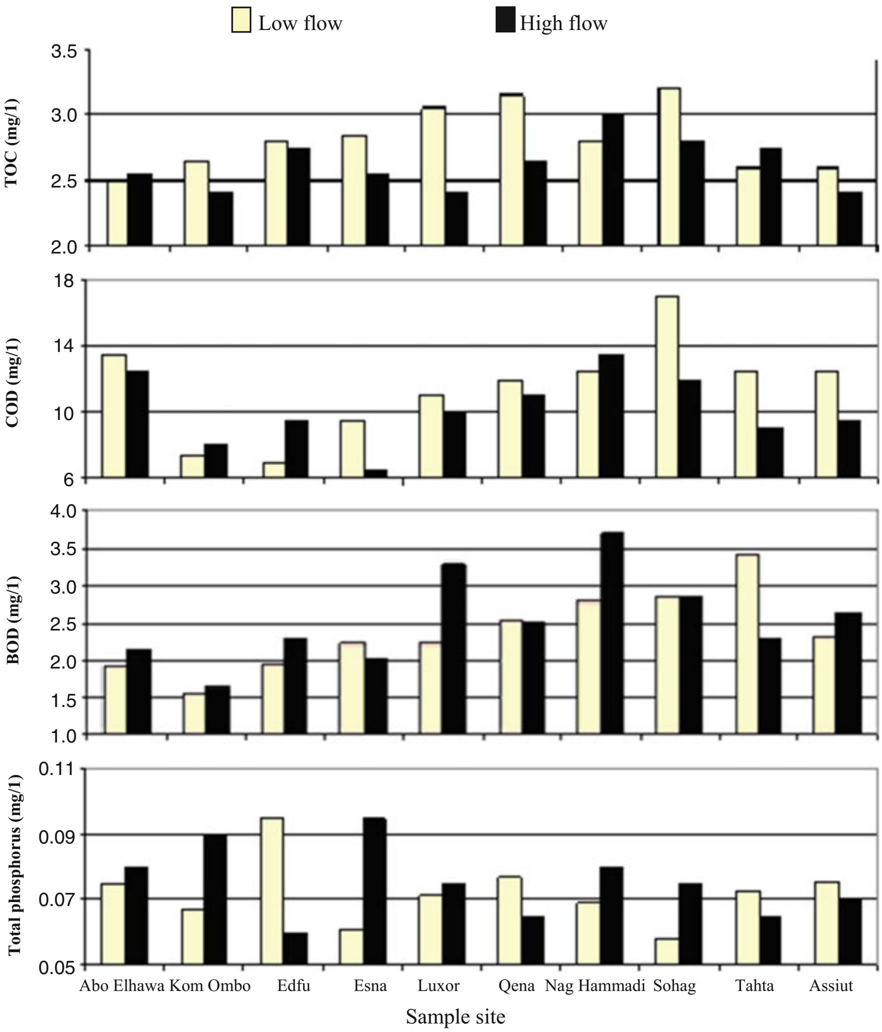

Fig. 7 Chemical characteristics of total phosphorous, biological oxygen demand (BOD), chemical oxygen demand (COD), and total organic carbon (TOC) along the Nile from Aswan to Assiut during low and high flow conditions (2011–2012)

4.1.11 Organic Matter

Biological Oxygen Demand

Oxygen concentration in water is very important for fish. It is worth mentioning that unpolluted waters typically have BOD values of 2 mg/l or less, whereas those receiving wastewater may have values up to 10 mg/l or more, particularly near to the point of wastewater discharge [29]. BOD in this study, recorded with increased values during high flow than during low flow (see Fig. 7). There was a slight decrease in BOD concentration during the low flow. The highest BOD value (3.72 mg/l) was measured at upstream Nag Hammadi Barrage during high flow period, while the lowest BOD value (1.56 mg/l) was recorded at Kom Ombo during low flow period. Low BOD values from Aswan to Luxor reflect low content of organic pollution.

Chemical Oxygen Demand

The COD is widely used as a measure of the susceptibility to oxidation of the organic and inorganic materials present in water bodies and in the effluents resulting from sewage and industrial plants [42]. The COD is higher during low flow than during high flow. Sohag shows the highest COD value (17.00 mg/l) during low flow and very low content of COD from Kom Ombo to Esna (see Fig. 7).

Total Organic Carbon

TOC in freshwaters arises from living material (directly from plant photosynthesis or indirectly from terrestrial organic matter) and also as a constituent of many waste materials and effluents [29]. The TOC content in the study area is higher from Luxor to Sohag (see Fig. 7) due to heavy population and human activity.

4.1.12 Major Ions

Cations (Na^+, K^+, Ca^{2+}, and Mg^{2+})

The most common major cations in the study area are Ca^{2+}, Na^+, Mg^{2+}, and K^+ (see Fig. 8). Calcium concentration along the study area at the River Nile ranged from 18.2 (Kom Ombo) to 23.2 mg/l (Tahta). It is the major cation of the Nile water, which probably comes mainly from the Ca-bearing rocks (Eocene and Late Cretaceous limestone and minor gypsum rocks of the Western Desert [43]). The average of sodium concentration is 15 mg/l. It does not change significantly from one place to another or from low flow to high flow. The average of magnesium concentration is 11 mg/l. The potassium cation occurs in low concentration (less than 6 mg/l) because K minerals are not common in the Ethiopian Highlands that are abundant with basaltic rocks. The K minerals (feldspars) are relatively resistant to weathering.

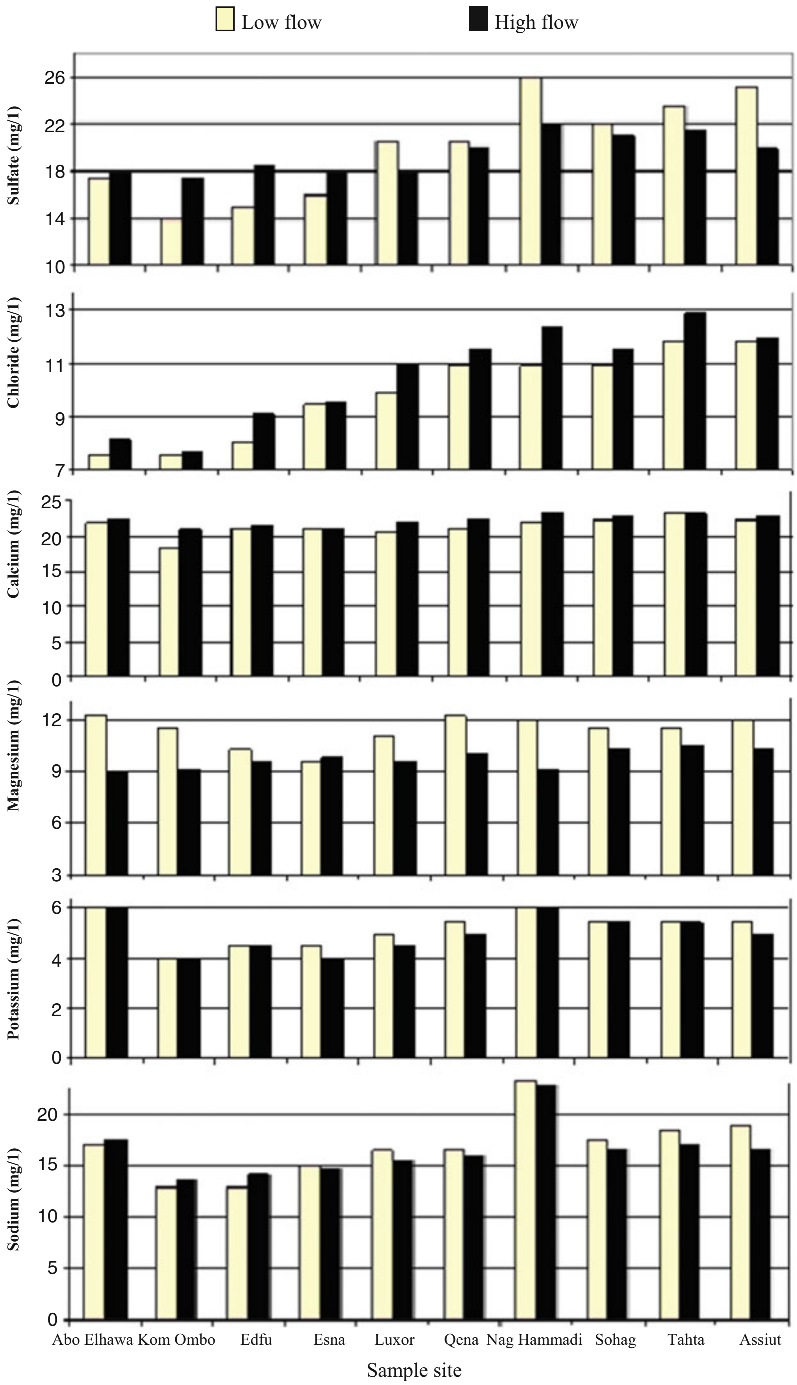

Fig. 8 Concentration of some major ions along the Nile from Aswan to Assiut during low and high flow conditions (2011–2012)

Anions (Cl^- and SO_4^{2-})

The major anions in the Nile water are chloride (Cl^-) and sulfate (SO_4^{2-}). The concentrations of the anions show an increase from Aswan to Luxor. They range from 7.5 to 26 mg/l (see Fig. 8). They are below the permissible limits of law 48 (less than 200 mg/l) and the guidelines of WHO (1993) (less than 200 mg/l).

4.1.13 Alkalinity

Alkalinity of natural water depends on soil and bedrock where it flows on. The main sources for natural alkalinity are rocks containing carbonate, bicarbonate, and hydroxide compounds. The most common constituents of alkalinity are bicarbonate (HCO_3^-), carbonate (CO_3^{2-}), and hydroxide (OH^-), which can originate from CO_2, and microbial decomposition of organic material. The total alkalinity obtained from the analysis of monitored sites recorded with increased values during low flow than during high flow, and spatially from Aswan to Assiut (see Fig. 9). It is found within the permissible limits of law 48/1982 (20–150 mg/l).

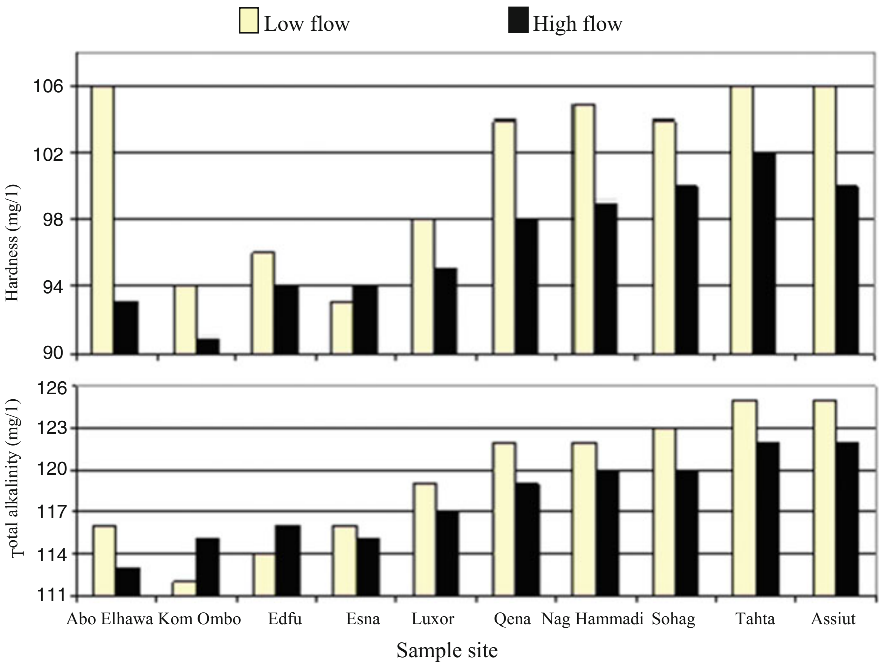

Fig. 9 Variation of total alkalinity and hardness along the Nile River during low and high flow conditions (2011–2012)

4.1.14 Hardness

The hardness of water is the traditional measure of the capacity of water to react with soap. It depends mainly on the presence of dissolved calcium and magnesium salts. The total content of these salts is known as general hardness, which can be further divided into carbonate hardness, and noncarbonate hardness [29]. Similar to the alkalinity, the hardness is recorded with increased values during low flow than during high flow, and spatially from Aswan to Assiut. It ranges from 91 to 106 mg/l (see Fig. 9). It is below the lower limit of WHO standard level (1993) which is 150 mg/l.

4.1.15 Heavy Metals

The term "heavy metal" refers to any metal and metalloid element that has a relatively high density ranging from 3.5 to 7 g/cm^3 and is toxic or poisonous at low concentrations [44]. They include mercury (Hg), cadmium (Cd), arsenic (As), chromium (Cr), thallium (Tl), zinc (Zn), nickel (Ni), copper (Cu), and lead (Pb). It is often used as a group name for metals and semimetals (metalloids) that have been associated with contamination and potential toxicity or ecotoxicity. Thus, the term "heavy metals" is both meaningless and misleading. Heavy metals are natural constituents of the earth's crust [45].

Sixteen heavy metal elements were measured in this study. However, many of these metals showed values less than the detection limits such as arsenic (<0.001 mg/l), vanadium (<0.005 mg/l), chromium (<0.001 mg/l), cobalt (<0.001 mg/l), antimony (<0.001 mg/l), selenium (<0.001 mg/l), and tin (<0.005 mg/l) during both flow periods. The low concentration values of the heavy metals in the Nile water are due to their deposition with sediments (silt) on the stream's bottom [46]. Also, analyses for aluminum, iron, manganese, zinc, cadmium, nickel, copper, lead, and barium were carried out for all water samples taken from the sites along the Nile River.

Lead (Pb)

Lead concentration in the Nile waters along the study area ranged from <0.001 to 0.007 mg/l and <0.001 to 0.015 mg/l during low flow and high flow, respectively (see Fig. 10). It is recorded mainly during high flow, indicating external source from the Ethiopian Highlands. The lead concentration lies within the permissible limits of law 48/1982 (<0.05 mg/l) and the guidelines of WHO (1993) (not to exceed 0.01 mg/l).

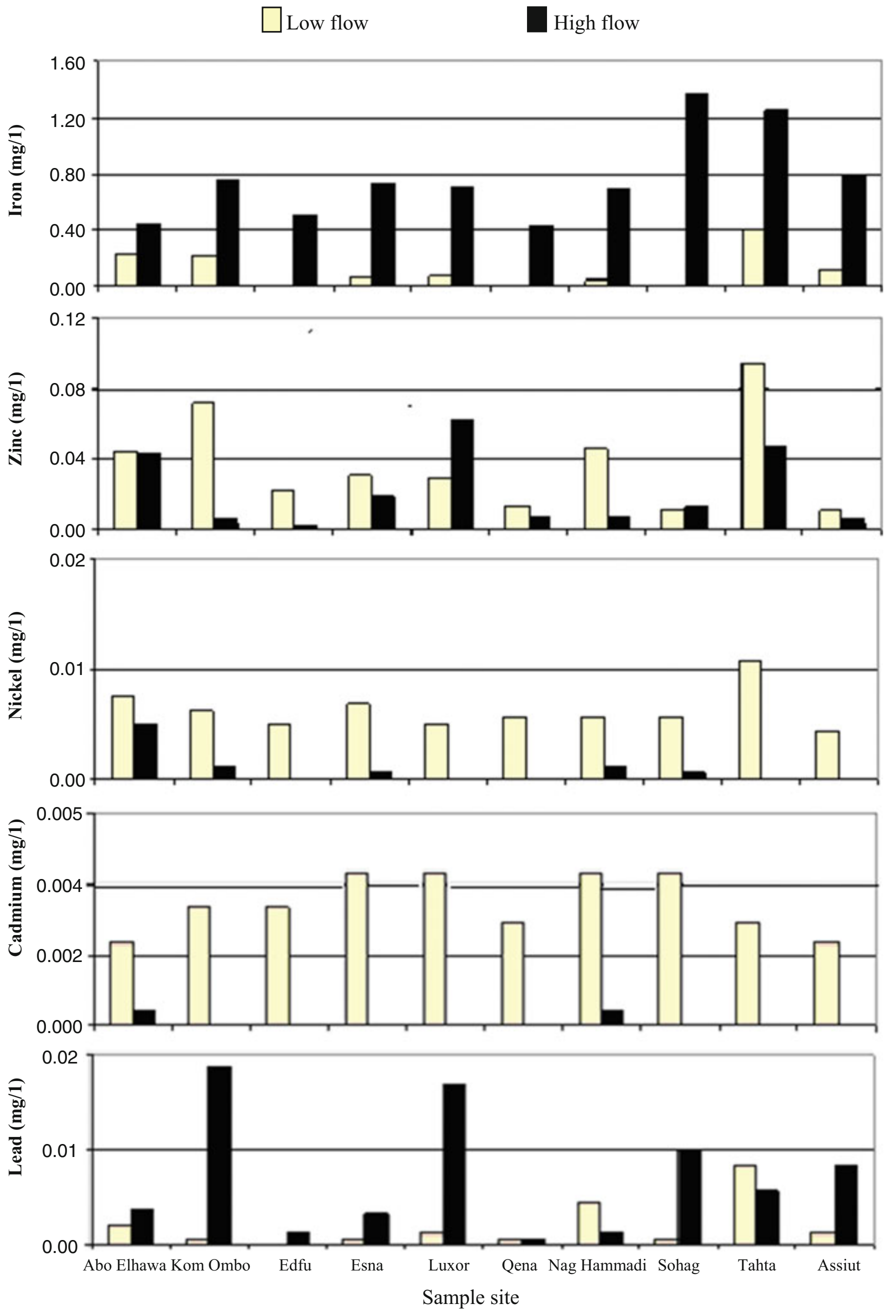

Fig. 10 Concentration of heavy metals (lead, cadmium, nickel, zinc, and iron) along the Nile from Aswan to Assiut during low and high flow conditions (2011–2012)

Cadmium (Cd)

Generally, the presence of cadmium in the water may be a result of geological source. Other sources are cadmium–nickel batteries, pesticide manufacture, and runoff from agricultural soils where phosphate fertilizers have been applied (Cd is a common impurity in phosphate fertilizers) [45]. The cadmium concentration in waters along the study area in the River Nile recorded low concentration below the detection limits during high flow. It is recorded mainly during low flow, ranging from <0.003 to 0.005 mg/l (see Fig. 10).

Nickel (Ni)

Nickel (Ni) is the 24th most abundant element in the earth's crust, comprising about 3% of the composition of the earth. The major source of Ni is the release from both natural sources and anthropogenic activity.

The nickel concentration in waters along the study area in the River Nile recorded values less than the detection limits (0.020 mg/l) during high flow. During low flow, nickel concentration ranged from <0.004 to 0.009 mg/l (see Fig. 10). The results of nickel were agreed within the permissible limits of law 48/1982 (<0.01 mg/l) and the guideline of WHO (1993) (<0.005 mg/l).

Zinc (Zn)

There are several major sources of zinc including both natural and anthropogenic sources. The primary anthropogenic sources are related to mining and metallurgic industry containing Zn. Along the study area in the River Nile, the zinc concentration ranged from <0.011 to 0.095 mg/l and <0.002 to 0.061 mg/l during low flow and high flow, respectively. In general, the concentration of Zn is relatively high during low flow (see Fig. 10), but still below the permissible limits of law 48/1982 (<1 mg/l) and the guideline of WHO (1993) (<5 mg/l).

Iron (Fe)

Iron (Fe) is the third most abundant metal in the earth's crust after silicon and aluminum, of which it accounts for about 5% with concentration of 50,000 ppm. Elemental iron is rarely found in nature, as the iron ions Fe^{2+} and Fe^{3+} readily combine with oxygen to form iron oxides. In the study area, the iron concentration ranged from <0.111 to 0.403 mg/l and from <0.445 to 1.371 mg/l during low flow and high flow, respectively (see Fig. 10). The concentrations of iron are within the permissible limits of law 48/1982 (<1 mg/l) and the guideline of WHO (1993), which is <1 mg/l.

Manganese (Mn)

The major sources of manganese (Mn) are ferromanganese production, organo-manganese fuel additives, welding rods, and municipal wastewater. Along the study area in the River Nile, the manganese concentration ranged from <0.005 to 0.093 mg/l and <0.048 to 0.705 mg/l during low flow and high flow, respectively (see Fig. 11). The results of manganese were agreed within the permissible limits of law 48/1982 (<0.5 mg/l) and the guideline of WHO (1993) (<0.5 mg/l).

Copper (Cu)

The primary sources are domestic wastewater, manufacturing processes involving metals, steam electrical production, the dumping of sewage sludge, and atmospheric deposition. Along the study area in the River Nile, the copper concentration ranged from <0.006 to 0.208 mg/l and <0.028 to 0.246 mg/l during low flow and high flow, respectively (see Fig. 11). They are within the permissible limits of law 48/1982 (<1.0 mg/l) and the guideline of WHO (1993) (<1.0 mg/l).

Barium (Ba)

The main sources of barium are the geologic deposits, industrial and municipal discharges. The barium concentrations in waters along the study area in the River Nile ranged from <0.051 to 0.069 mg/l and <0.037 to 0.065 mg/l during low flow and high flow, respectively (see Fig. 11). They are within the permissible limits of law 48/1982 (<1.0 mg/l) and the guideline of WHO (1993) (<0.7 mg/l).

Aluminum (Al)

Aluminum is the second most abundant metal in the earth's crust after silicon, of which it accounts for about 8% with concentration of 80,700 ppm. The main source of aluminum to get into surface waters is leaching from Al-bearing minerals. The aluminum concentrations in waters along the study area in the River Nile ranged from <0.052 to 0.634 mg/l and <0.164 to 0.748 mg/l during low flow and high flow, respectively (see Fig. 11). In many sites, the concentrations of Al are higher than the maximum contaminant level (MCL) for drinking water (0.05–0.2 mg/l), especially in Nag Hammadi because of the Aluminum Factory.

4.1.16 Biological Characteristics (Fecal Coliform)

Fecal pollution is a major concern for many rivers where it can originate from human sources and nonhuman sources. The fecal coliform was recorded with

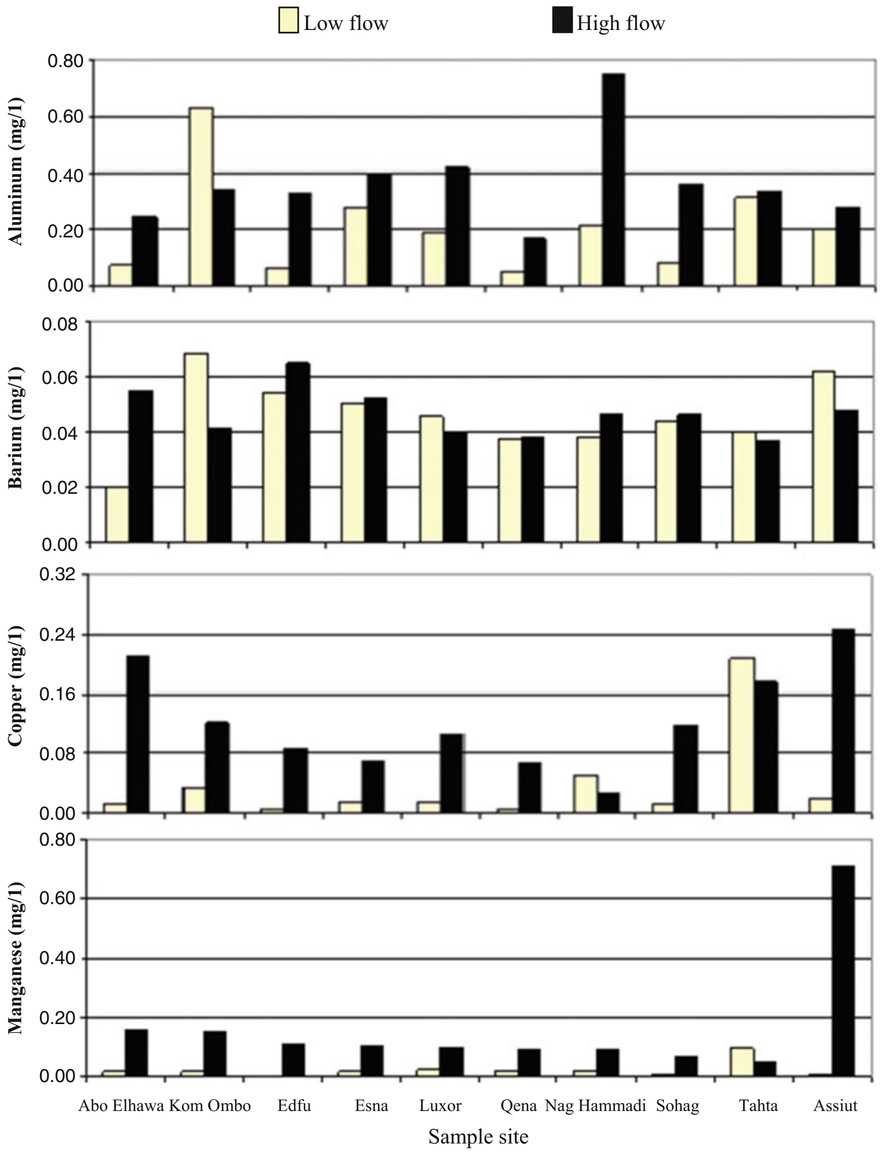

Fig. 11 Concentration of heavy metals (manganese, copper, barium, and aluminum) along the Nile from Aswan to Assiut during low and high flow conditions (2011–2012)

increased values during low flow than the high flow. It is recorded in all sites especially Edfu, Nag Hammadi, and Tahta where the high levels of organic pollution exist (see Fig. 12).

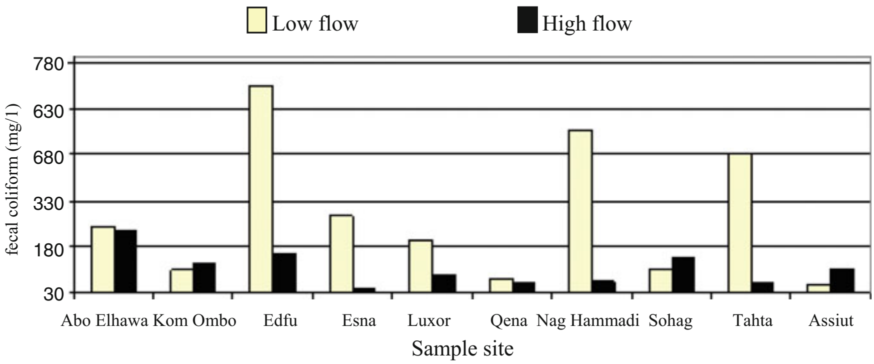

Fig. 12 Concentration of fecal coliform along the Nile from Aswan to Assiut during low and high flow conditions (2011–2012)

4.1.17 Residual Sodium Carbonate

Residual Sodium Carbonate (RSC) is another alternative measure of the sodium content in relation with Mg and Ca. RSC is calculated by Eaton (1950) equation:

$$\mathrm{RSC} = \left(\mathrm{CO_3}^{2-} + \mathrm{HCO_3}^{-}\right) - \left(\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+}\right)$$

The concentration of the ions in milliequivalents per liter of water. If the RSC $<$ 1.25, the water is considered safe and if the RSC $>$ 2.5, the water is not appropriate for irrigation.

The result in the study area in low and high flow condition showed that the recorded value of RSC less than 1.25 that means it is safe for irrigation.

4.1.18 Soluble Sodium Percent

The Soluble Sodium Percent (SSP) was also used to evaluate sodium hazard. It is defined as the ratio of sodium to the total cation multiplied by 100 [47]. The SSP greater than 60% may result in sodium accumulations that will cause a breakdown in the soil physical properties. The calculated values of SSP along the study area in the Nile River ranged between 21.84% to 31.19% and 23.54% to 32.57% in low and high flow condition indicating that sodium could not affect the soil structure, its infiltration and permeability characteristics.

4.2 Sediment Quality

4.2.1 Grain Size Distribution

The results of the grain size distribution analyzed for the bed sediments of four sites (see Fig. 1) showed that: During February, the grain size distribution at Abo Elhawa site and Assiut Barrage is classified as medium to fine sand in texture. The upstream Esna Barrage area is classified as fine to medium sand in texture. The area located upstream Nag Hammadi Barrage is classified as fine sand. While during August, the area located upstream Nag Hammadi and Assiut Barrage is classified as fine sand. The area located upstream Esna Barrage has medium sand. However, the grain size distribution at Abo Elhawa site is classified as medium to coarse sand (see Tables 3 and 4). Several efforts have been undertaken by many authors to develop standard procedures and criteria for the assessment of environmental impacts on sediments.

4.2.2 Sediments Quality Assessment

In this chapter, the assessment was conducted by comparing the average total heavy metals concentration with the permissible values of different sediment quality objectives (see Table 5).

The results of this simple comparison revealed that the upstream Nile barrages bed-sediment concentrations were found within the permissible limits of standards

Table 3 Grain size distribution during low flow

Sites	% Gravel	%Sand				% Silt	Classification
		Coarse	Medium	Fine	Total		
Abu Elhawa	1.44	0.95	60.40	36.52	97.88	0.68	Medium to fine sand
Esna Barrages	0.00	1.04	44.84	50.99	96.87	3.13	Fine to medium sand
Nag Hammadi Barrages	0.00	1.11	18.35	76.93	96.39	3.61	Fine sand
Assiut Barrages	0.00	4.95	57.62	35.32	97.89	2.11	Medium to fine sand

Table 4 Grain size distribution during high flow

Sites	% Gravel	%Sand				% Silt	Classification
		Coarse	Medium	Fine	Total		
Abu Elhawa	9.31	33.80	51.34	5.38	90.53	0.16	Medium to coarse sand
Esna Barrages	5.42	18.17	65.27	11.03	94.46	0.12	Medium sand
Nag Hammadi Barrages	0.00	2.94	26.95	64.56	94.46	5.54	Fine sand
Assiut Barrages	0.00	0.41	28.07	71.20	99.68	0.32	Fine sand

Table 5 Concentration of some heavy metals in the Nile water and bed sediments compared to the Canadian regulatory standards for agricultural soil (mg/kg)

Metal	Nile water (mg/l)		Nile bed sediments (mg/kg)		Canadian standards
	Low flow	High flow	Low flow	High flow	
Cr	0.407	0.116	101.75	115.5	250
Cu	0.665	0.831	568.25	565.38	150
Ni	N.D	0.374	3.38	41.5	100
Pb	N.D	0.314	2.75	32.75	200
Zn	1.327	0.458	1056.5	119	500

for nickel and lead during both flow conditions and zinc during high flow condition. However, chromium and copper exceeded the permissible limits during both flow conditions.

4.2.3 Bioavailability of Heavy Metals in the River Nile Recent Bed Sediments

Bioavailability is the proportion of total metals that are available for incorporation into biota (bioaccumulation). Total metal concentrations do not necessarily correspond to metal bioavailability. Bioaccumulation of metals by biota in surface water and by plants and animals in terrestrial environments can adversely affect humans [48]. Partition of the total metal concentrations into non-residual and residual fractions or phases is used in sedimentary geochemistry to provide information regarding the binding sites of metals as well as their source and pathways by which they have been transported to the aquatic environment. The non-residual also known as non-lithogenous or non-detrital fraction is considered to be mobile or environmentally reactive fraction in respect of geological and chemical processes.

The partitioning of metals associated with the non-residual fractions was notably lower than those of the residual fraction (see Figs. 13 and 14). The metals are primarily derived from geochemical background. Heavy metals are relatively stable where the metals are associated with the residual form and the sediment is relatively unpolluted. Several authors [49] have confirmed that the high proportion of metals in the residual fraction indicates that the sediment is relatively unpolluted. This will cause a decrease in the ability of soil to form stable aggregates and a loss of soil structure and tilth. This will also lead to a decrease in infiltration and permeability of the soil to water leading to problems with crop production.

5 Conclusions and Recommendations

The water quality along the Nile River from Aswan to Assiut changes from low to high flow and from one place to another according to human activities. The water pollution increases with the distance from the AHD to the north due to untreated

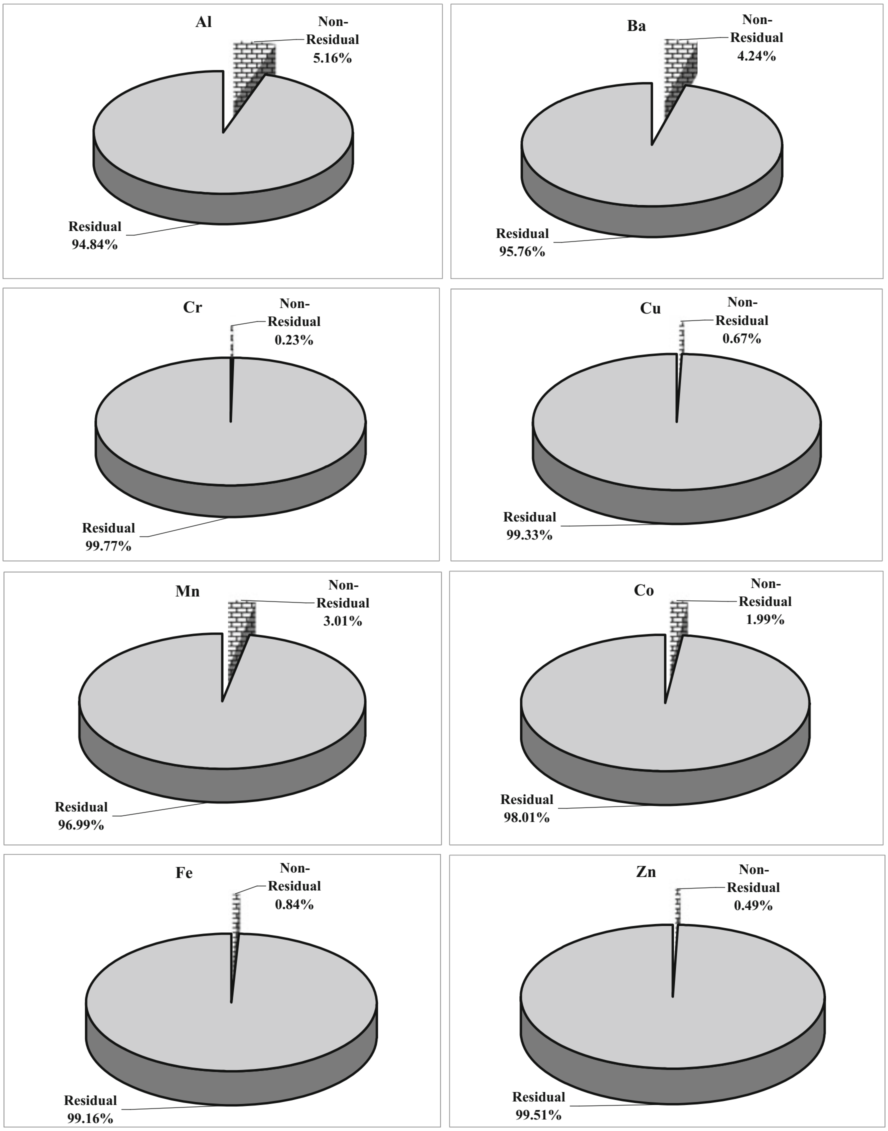

Fig. 13 Average percentage of heavy metals fractionation in bottom sediment along the Nile River during low flow condition (2011–2012)

agricultural drainage water flowing by gravity back to the Nile. The three major sources of Nile water pollution in the study area are industry, agriculture and household waste. The results can be extended to all sites along the Nile up to the northern coast. Although the Nile water in general is suitable for human consumption after regular treatments in water stations, some harmful pollutants were recorded such as heavy metals and fecal coliform bacteria especially during low flow periods.

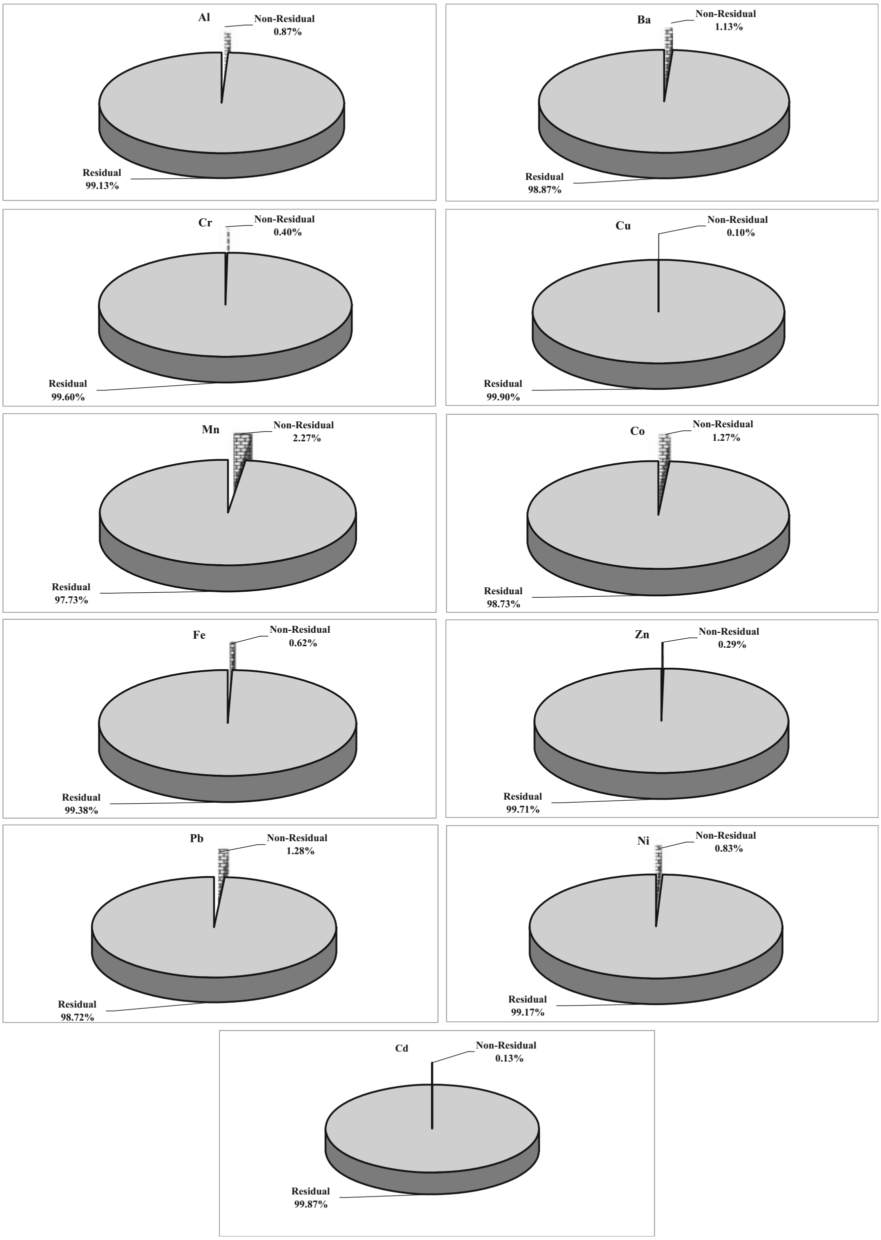

Fig. 14 Average percentage of heavy metals fractionation in bottom sediment along the Nile River during high flow condition (2011–2012)

It is strongly recommended to fully treat agricultural drainage before flowing to the Nile. Sewage water from some villages and Nile hotels are responsible for the occurrence of fecal coliform bacteria recorded in all sites. It is highly recommended to minimize the period of winter maintenance of the AHD and the irrigation water channels, when most of the heavy metals and organic pollutants increase. Further studies are needed to document the effect of each agricultural drain or industrial factory on the Nile.

References

1. NBI (2016) Nile Basin water resources atlas, Nile Basin Initiative (NBI). New Vision Printing and Publishing Company Ltd., Kampala, Uganda, p 201
2. PRB (2016) 2016 World Population Data Sheet. Population Reference Bureau: www.prb.org. Accessed in Nov 2016
3. Mckee JE, Wolf HW (1971) Water quality criteria, 2nd edn. State Water Resources Control Board Publication, No. 34, California, pp. 23–25
4. Fishbein L (1974) Water pollution by pesticides. J Fish Biol 56:269–279
5. Gibbs J (1972) Water chemistry of the Amazon River. Geochim Cosmochim Acta 36:1061–1066
6. Stroomberg GJ, Freriks IL, Smedes F, Colino WP (1995) In: Quevauviller P (ed) Quality assurance in environmental monitoring. VCF, Weinheim
7. Abdel-Aal SI, Shahin RR, Abdel-Hamid MA, Abdel-Tawab MM (1988) Impact of liquid wastes of industrial complex at Helwan on water quality of both Nile and Canal stream. Egypt J Soil Sci 28(4):421–432
8. Mahrous YM (1997) Sources of River Nile water pollution from Assiut to Cairo and the evaluation of its effect on the water quality. J Environ Sci 13:45–65
9. Abdel-Satar AM (2005) Quality of River Nile easements from Edfu to Cairo. Egypt J Aquat Res 31(2):182–199
10. Abdel-Rehim SS, Heikal MT, Mageed AA, Kassem HA, Talaat A (2006) Detection of pollution in some locations of the Nile ecosystem using abiotic and biotic index. J Environ Sci 13:325–349
11. Abo El-Hassan WH, Mostafa MM, Fujimaki H, Inoue M (2009) Irrigation improvement assessment from the water quality and human health perspective in the Nile Delta, Egypt. J Food Agric Environ 7:815–822
12. Shehata SA, Badr SA (2010) Water quality changes in River Nile Cairo, Egypt. J Appl Sci Res 6(9):1457–1465
13. Yousry M, Awadaalah AG, Sallem T (2011) Assessment of Nile water quality data using exploratory data analysis and clustering of variables. Geosci Res 2:49–60
14. Abtew W, Melesse AM (2014) The Nile River basin, ch. 2. In: Melesse AM, Abtew W, Setegn S (eds) Nile River basin: ecohydrological challenges, climate change and hydropolitics. Springer International Publishing, Switzerland, pp. 7–21
15. El-Kammar AM, Ali BH, El-Badry AM (2009) Environmental geochemistry of River Nile bottom sediments between Aswan and Isna, Upper Egypt. J Appl Sci Res 5:585–594
16. Shukri NM (1950) The mineralogy of some Nile sediments. Quat J Geol Soc London 105:511–534
17. El-Kammar AM, Philip G, Arafa EH (1992) Geochemistry of Recent Nile sediments from the main Nile course in Egypt and the principal tributaries in Ethiopia and Sudan. In: Proceedings of the 1st international conference on the geology of the Arab World. Cairo University, Egypt, pp 527–541
18. Said R (1993) The River Nile. Pergamon, Oxford 320 pp
19. Abdel-Fattah S, Amin A, Van Rijn LC (2004) Sand transport in Nile River, Egypt. J Hydraul Eng 130(6):488–500

20. Garzanti E, Andò S, Vezzoli G, Abdel Megid A, El Kammar A (2006) Petrology of Nile River sands (Ethiopia and Sudan): sediment budgets and erosion patterns. Earth Planet Sci Lett 252:327–341
21. Issa S, Yosif M, Elsaman R (2013) Gamma radioactivity measurements in Nile River sediment samples. Turkish J Eng Env Sci 37:109–122
22. Arafa WM, Badawy WM, Fahmi NM, Ali K, Gad MS, Duliu OG, Frontasyeva MV, Steinnes E (2015) Geochemistry of sediments and surface soils from the Nile Delta and lower Nile valley studied by epithermal neutron activation analysis. J Afr Earth Sci 107:57–64
23. Woodward JC, Williams MAJ, Garzanti E, Macklin MG, Marriner N (2015) From source to sink: exploring the Quaternary history of the Nile. Quat Sci Rev 130:3–8
24. Shahin M (2002) Hydrology and water resources of Africa. Springer, Kluwer Academic Publishers, New York 659 pp
25. MWRI (2015) MWRI website. Ministry of Water Resources and Irrigation. www.mwri.gov.eg/en/. Accessed in Nov 2016
26. Ahmed AA, Ismail UH (2008) Sediment in the Nile River system. UNESCO-IHP-International Sediment Initiative, UNESCO, p 93. http://www.irtces.org/isi/isi_document/Sediment%20in%20the%20Nile%20River%20System.pdf. Accessed in Oct 2016
27. APHA-AWWA-WPCF (1992) Standard methods for the examination of water and wastewater, 18th edn. American Public Health Association, American Water Works Association and Water Pollution Control Federation, Washington, DC
28. Awadallah RM, El-Haty MT, Soltan ME, Ahmed IA (1991) Characterization of the Nile water quality in the zone from Aswan to Giza Delta. J Sci 15(1):84–104
29. Chapman D (1992) Water quality assessments, 1st edn. Chapman and Hall, London and New York
30. Ayers RS, Westcot DW (1985) Water quality for agriculture. In: Food and Agricultural Organization of the United Nations (FAO), irrigation and drainage paper 29 rev. 1. FAO, Rome
31. Ewnetu DA, Bitew BD, Chercos DH (2014) Determination of surface water quality status and identifying potential pollution sources of Lake Tana: particular emphasis on the lake boundary of Bahirdar City, Amhara region, north west Ethiopia, 2013. J Environ Earth Sci 4(13):88–97
32. Rzoska J (1976) The Nile, biology of an ancient river, vol 29. DR. W. Junk B.V., Publishers, The Hague 417 pp
33. Schluter T (1997) Geology of East Africa, Berlin. Gebruder Borntraeger, Berlin-Stuttgart 484 pp
34. Allem AA, Samman AA (1969) Productivity of Lake Mariut, Egypt, part I. Physical and chemical aspects. Int Revue ges Hydrobiol 54:313–355
35. El-Wakeel SK, Wahby SD (1970) Hydrography and chemistry of Lake Manzala, Egypt. Arch Hydrobiol 67:173–200
36. WHO (1993) Guidelines for drinking-water quality, Second editon. Volume 1: Recommendations. World Health Organization, Geneva, p 188
37. FAO (1985) Water quality guidelines for surface irrigation.
38. Cole GA (1979) Textbook of limnology. Mosby, St. Louis 283 pp
39. El-Gamel A, Shafik Y (1985) A study on the monitoring of pollutants discharging to the River Nile and their effect on the River water quality. Water Qual Bull 10:101–106
40. Klein L (1973) River pollution, part 1, chemical analysis, 5th edn. Butterworths, London
41. Morel FMM (1983) Principles of aquatic chemistry. Wiley, New York
42. Peavy HS, Rowe DR, George T (1986) Environmental engineering. McGraw-Hill Book, Singapore
43. Said R (1981) The geological evolution of the River Nile. Springer, Heidelberg
44. Gautam RK, Sharma SK, Mahiya S, Chattopadhyaya MC (2014) Contamination of heavy metals in aquatic media: transport, toxicity and technologies for remediation. In: Heavy metals in water: presence, removal and safety. The Royal Society of Chemistry, Cambridge, pp 1–24. doi:10.1039/9781782620174-00001

45. Duffus JH (2002) Chemistry and human health division clinical chemistry pure. Appl Chem 7 (5):793–807
46. Thornton JA, Rast W, Holland MM, Jolankai G, Ryding SO (1999) Assessment and control of nonpoint source pollution of aquatic ecosystem. Parthenon Press, Man and the Biosphere Series (MAB), vol. 23. UNESCO, Paris, p 455
47. Eaton FM (1950) Significance of carbonates in irrigation waters. Soil Sci 39:123–133
48. Davis A, Ruby MV, Bergstrom PD (1994) Factors controlling lead bioavailability in the Butte mining district, Montana, USA. Environ Geochem Health 3:147–157
49. Akcay H, Oguz A, Karapire C (2003) Study of heavy metal pollution and speciation in Buyak Menderes and Gediz River sediments. Water Res 37:813–822

Morphology of the Nile River due to a Flow Rate over the Maximum Current: Case Study Damietta Branch

Abdelazim Negm, Tarek M. Abdel-Aziz, Mohamed N. Salem, and Wessam Yousef

Abstract Damietta branch is one of the two branches of the Nile River. It is the main source of water for water supply for both domestic and industrial activities, irrigation and navigation purposes in the Nile Delta region and its fringes, Egypt along with the Rosetta branch. Field investigations proved that scour, deposition, and bank erosion occurred along the course of the branch. Also, encroachment by people on the flood plain during the last three decades led to a reduction in its carrying water capacity. Therefore, this chapter aims at presenting the results of a numerical investigation on the effect of passing a higher future discharge more than the maximum current flowing discharge. Two-dimensional hydrodynamic mathematical model (CCHE2D) was used to simulate the morphological changes in Damietta branch due to an additional excess flow of 20 Mm^3/day. Also, the CCHE2D was used to predict the effect of high flows on water velocities and geometrical changes at different cross sections. Comparisons between cross sections under the scenario of increasing the discharge from 60 to 80 million m^3/day were carried out. Moreover, the side effects on the navigational channel and overtopping problems had been investigated. Consequently different solutions were suggested to increase the ability of Damietta branch to convey higher discharges.

A. Negm (✉) and M.N. Salem
Water and Water Structures Engineering Department, Faculty of Engineering, Zagazig University, Zagazig 44519, Egypt
e-mail: amnegm@zu.edu.eg; amnegm85@yahoo.com; mnsa30@yahoo.com

T.M. Abdel-Aziz
Nile Research Institute, National Water Research Center, El Qanater 13621, Egypt
e-mail: aziztm@hotmail.com

W. Yousef
Ministry of Housing, Utilities, and Urban Development, Cairo, Egypt

A.M. Negm (ed.), *The Nile River*,
Hdb Env Chem (2017) 56: 239–258, DOI 10.1007/698_2017_3,

Keywords CCHE2D, Damietta Branch, Hydrodynamics, Navigation, Nile morphology

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1 Introduction

Investigating the morphology of rivers is of great importance to maintain the river regime fixed as much as possible to create safe environment for activities such as navigation and sustainable stream. However, after the construction of dams across the river to store water for irrigation, water supply, flood control, generation of water power, navigation, or recreation, the sediment transport capacity to the downstream of the dam is reduced.

In case of Aswan High Dam on the River Nile in Egypt, the effect of the dam on the Nile River was summarized by Gaweesh and Gasser [1] in Table 1.

After constructing the dam, the water released from the dam reservoir is almost sediment free and hence it picks up sediment from the bed and banks of the stream causing degradation over long reaches of the stream. Also, passing higher discharge than the maximum designed ones may alter the river morphology. It may also lead to channel widening or change in the plan form of the river [2]. A recent study [3] focused on three river segments, separated at the confluences with two tributaries, Plum Creek and Long Pine Creek. With an overall temporal scope of 1988–2010 that includes a short interval preceding and a long interval following the Niobrara National Scenic River Designation Act of 1991. The study analyzed five separate time periods: 1988–1993, 1994–1999, 2000–2003, 2004–2006, and 2007–2010, each of which ended with a year in which aerial photography coverage was available. Changes in channel morphology were examined using aerial photographs from 1993, 1999, 2003, 2006, and 2010 to measure channel width, area of islands, and incipient flood-plain surfaces, and to compute the braided index. Channel metrics were computed for each photography year and summarized by river

Table 1 Effect of dam construction on the Nile River [1]

Items	Before AHD	After AHD
Discharge (Q) downstream dam	Reach to 800 million m^3/day during the flood season	The maximum value of about 270 million m^3/day at present
Water surface slope	5–10 cm/km depending on the flow discharges and upstream, downstream, water levels at the intermediate barrages	Decreased to a range 4.8–8.4 cm/km due to reduction in the discharges
Depth of water	As a consequence of the reduction that occurred in the discharge, the flow depth has been significantly reduced except for low flows within thalweg lines	
Velocity	The range of velocities is reduced depending upon the reduction that occurred in the flow discharge and depth	
Size of bed materials	Increased over time due to sorting of the bed material and clear water released from AHD	
Grain roughness	Enlarged as a result of increase that occurred in median diameter of the bed material	
Bed material discharge Qs	Reduced due to the limited discharges and because of trapping the sediment in the reservoir upstream of AHD	
Sinuosity	Increased in consistence with reduced discharges, increased channel roughness at low flows and relatively mild channel slopes	

segment. Additionally, at fixed-location cross sections, photography analysis identified localized geomorphic change to infer processes. Accuracy of geomorphic feature classification was estimated and the root-mean-square difference (RMSD) between aerial photographs was calculated to determine associated errors in channel metric calculations. The horizontal accuracy of boundaries delineated in the classification was estimated as 5 m for boundaries based on 1993 aerial photography and 4 m for all other aerial photography. The RMSD between aerial photography years ranged from 3.04 to 4.16 m.

In Egypt, on the other hand, several investigations were conducted to deal with the effect of Nile river extra discharges on river morphology and bank erosion [4–14]. It was concluded that there was non-uniform erodability of the bank [15]. The meander morphologies of Damietta Branch were investigated by Moustafa [16] at 1982 and 2001 using GSTARS2 model. The investigated parameters include channel width, channel depth, and meander wave length. The reach has features such as meandering, bends, and islands. It was concluded that due to the increase of flow, the average rate of degradation was 14.91 cm/km while the average rate of aggradations was 10.62 cm/km. Also, the morphological changes were studied by Abdel-Naby [17] to investigate its effect on different parameters such as channel plan form, width, erosion, and deposition near the embankments of the River Nile at the area of Kasr El-Nile. The purpose of the investigation was to suggest measures to protect the water structures and river banks. The Surface water Modeling System (SMS) was used during the modeling processes. It was concluded that the rate of average velocity tends to be higher at the East side rather than the West side. The rate of deposition was high and caused navigation problems. For the reach from

Sohag to El-Minia, Ahmed and Fawzi [18] dealt with meandering and bank erosion of the River Nile and its environmental impacts. The analysis of Landsat imagery revealed the migration of river course with time and space. Some islands disappeared completely in the study area whereas new islands appeared. The lateral erosion on the river banks led to a decrease in agricultural lands bordering the river banks and a decrease in the areas of the river islands which in turn reduced the agricultural production. Protection methods were recommended to protect the river bank from further movement and erosion. River control was recommended to weaken the secondary currents created by the river bends. It was recommended to regularly monitor the river banks and islands and measure the rates of erosion and deposition. Sand bars and subsurface islands should be monitored and identified with flash lights to mitigate navigation problems. Also, the fourth reach of the Nile River located between Assiut Barrage (km 544,500 downstream the Aswan Dam) and the Delta Barrage (km 954,500) was studied by Mostafa [19]. The morphological changes were analyzed with respect to the future expected low and high flows on potable water and power plant stations and navigation problems. Scenarios were considered to study the effects of high flows to locate the areas that will be inundated and to predict the morphological changes. The GSTARS3 model and others were used to simulate the water surface profile and the sediment transport. It was concluded that deposition had more frequent occurrence than erosion on the bed for the whole reach during the past decades. For future discharges, the application of low flows scenarios resulted in 15 water stations and 8 potable water stations will be affected by passing the discharges of 35 and 39 Mm^3/day, respectively. The water levels at these stations will be below the critical level of the stations' operation. Also, two other locations were identified to have navigational bottlenecks in case of passing these low flow rates (39 and 35 Mm^3/day). For the application of the high flows scenarios of high flows, the total lengths of the inundated regions at both banks will be about 79.89, 26.06, and 15.01 km for the discharges 350, 200, and 190 Mm^3/day, respectively. The expected areas of the inundated regions might be 4,777, 962, and 448 feddans (1 feddan = 4,200 m^2). The Nile River reach from Esna Barrage to Naga Hammadi Barrage; about 192 km length was studied for the period from the year 1982 to the year 2005 [20]. The investigation focused on the hydraulic impacts due to erosion, sedimentation, and over topping on the Nile River. About 26 cross sections were selected along the study reach with space of 4 km. The GSTARS model was used in the simulation. These cross sections were used to compare the results of simulation for the year 1982 and the year 2005 in order to calculate erosion and sedimentation quantities. Finally cross sections of the year 2005 were used to develop water surface profile and to map the overtopping areas by applying a future discharge of 4,051 m^3/s using topographic maps. It was concluded that 16 sections out of 26 were affected by overtopping.

For Damietta branch, Moussa and Aziz [21] compared the performance of several sediment evaluation equations of Ackers and White, Engelund and Hansen and Yang to predict the amount of sediment discharges in the Nile River at Damietta branch in the period from 1982 to 2001. They found that the equations of Ackers, White, and Yang produced comparable results with a predicted percentage of 76.34%. The rate of error for the cross sections is small for Ackers and White equation compared to the other two equations. Also, the morphological changes in the Delta Barrages area (Damietta and Rosetta Branch) were analyzed to emphasize the aggradations in the 40 km upstream of Delta Barrages [22]. The degradation in the downstream area extends to 10 km along the two branches. The hydrographic survey of the river bed in 1982 and 2002 was used in building the model. It was found that there was a rising in the bed level upstream Delta Barrage of about 1.5 m in some places and increasing in its width and depth along the study reach [22].

This chapter aims at investigating the impact of increasing the flow rate from the current maximum of 60 Mm^3/day to the expected in the future of 80 Mm^3/day on the meandering geometry of Damietta branch reach of the Nile River from downstream Delta Barrage up to Zefta Barrage. The CCHE2D model [23] is adopted for the morphological study to propose the location of protection works to avoid the banks overtopping and satisfy the navigation requirements.

2 Study Area and Field Data Collection

Damietta branch (see Fig. 1) is one of the two River Nile branches (Damietta and Rosetta branches). It is considered an important water way through the River Nile. It extends from downstream Delta Barrages at km 26.5 behind EL-Roda Gauge station to the Mediterranean Sea with length about 245 km. It has an average width of about 280 m and average sinuosity about 1.3. The water surface slope of

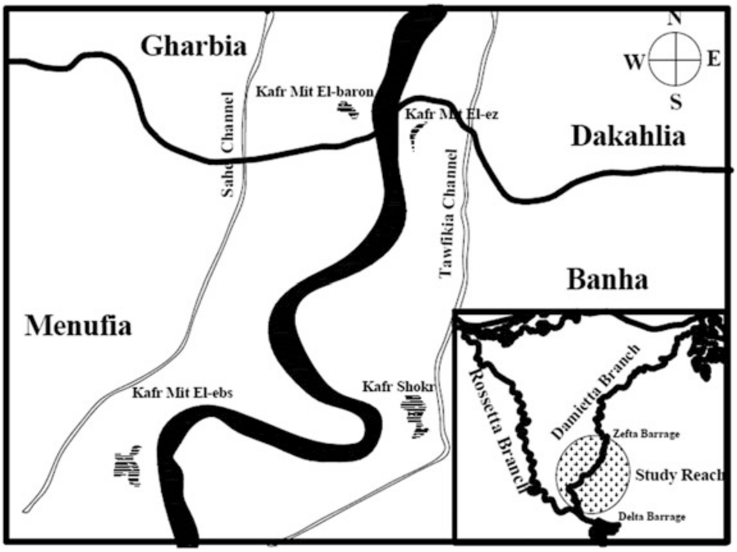


Fig. 1 The Damietta branch topography [24]

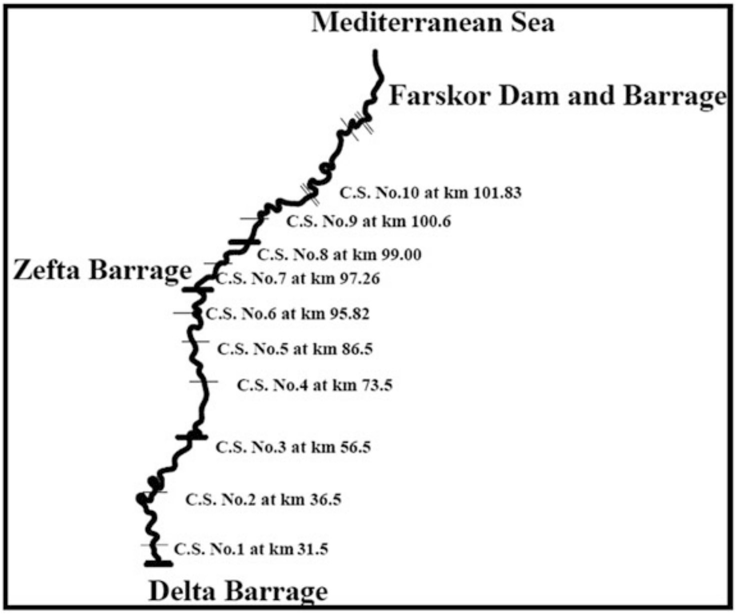


Fig. 2 Location of cross sections (C.S.) along the study area where the measurements were done [24]

Damietta branch from Delta Barrage to Zefta Barrage (119.85 km from EL-Roda Gauge station) is about 5.5 cm/km in case of high flow and 3.8 cm/km in case of low flow. But the water surface slope downstream Zefta Barrage is about 2.7 cm/km in case of high flow and 2.4 cm/km in case of low flow. Delta Barrage is replaced by a new Barrage on Damietta branch in 1982 downstream the existing one, which is located at 27.3 km from EL-Roda Gauge with five vents (openings). The width of each vent is 5.25 m while the pier's width is 1.5 m. The flow rate through the reach is 22 Mm^3/day. This branch is morphologically unstable and comprises many local changes by hydraulic characteristic changes and morphological changes as scour, deposition, and bank erosion. Additionally, encroachment by people on the flood plain during the last three decades was observed. The result is the capacity of the river to convey high discharges was reduced. In this study, the considered reach is 90 km length starting at km (26.5) and ends at km (116.5) and contains ten cross sections (see Fig. 2).

3 Collection of Field Data

The collected data (e.g., bed levels, velocities, discharges, and suspended sediment concentration) were obtained from two institutes, the Nile Research Institute (NRI) and Hydraulic Research Institute (HRI) that belong to the National Water Research

Center (NWRC), Ministry of Water Resources and Irrigation, Egypt [4–8]. The NRI and HRI performed a complete hydrographic survey and collected the data of the water levels, corresponding passing discharges, and suspended sediment concentration for Damietta branch as well for the whole Nile River. The selected reach consists of many successive meandering curves where point bars and pools are the common bed forms and composed of a relatively homogeneous combination of fine sand and silt. The river free surface width is varied between a maximum width of about 365.07 m at km 101.83 downstream EL-Roda Gauge and a minimum width of about 244.6 m at km 95.82 downstream EL-Roda Gauge. Figure 2 shows the locations of cross sections where the velocities, bed levels, and water levels were measured.

The average velocities at ten sections were computed based on actual measurements of velocities at vertical line for each section. At each vertical location the velocity was measured at five depths along the specified locations (0.5 m under the surface water, 25%, 50%, 75% of the total depth, and 0.75 m above the river bed) as shown in Fig. 3. Table 2 shows the computed average velocities at the ten cross sections. The bed material samples were collected at the ten cross sections along the

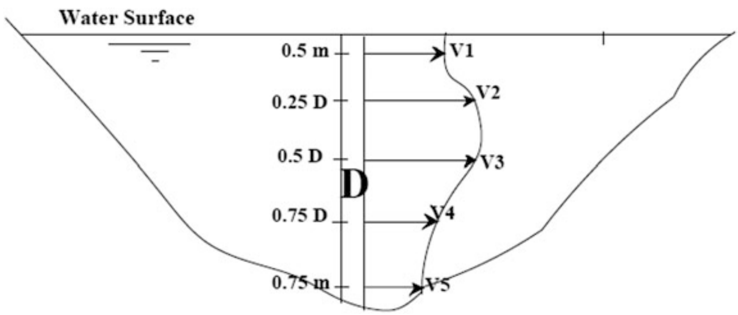


Fig. 3 Computation of the average velocity at any section [24]

Table 2 The average velocity along the study area [24]

C.S. No.	Distance downstream EL-Roda Gauge (km)	Date	Average velocity (m/s)
1	31.50	14/12/2003	0.71
2	36.50	13/12/2003	0.77
3	56.50	10/12/2003	0.79
4	73.50	10/12/2003	0.69
5	86.50	10/12/2003	0.59
6	95.82	23/4/2003	0.52
7	97.26	24/4/2003	0.50
8	99.00	28/4/2003	0.50
9	100.6	20/12/2003	0.49
10	101.83	22/12/2003	0.41

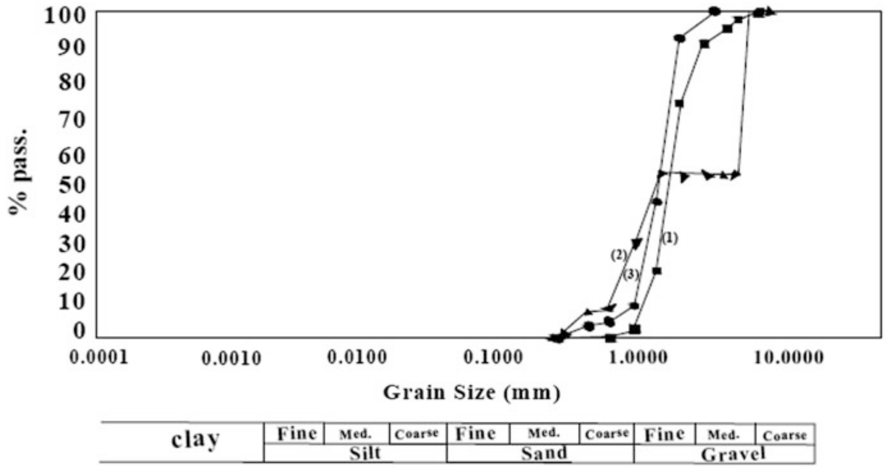


Fig. 4 Typical grain size distribution curves at C.S. No. (6) for three samples [24]

study reach from data gathered by NRI. The grain size distribution curves at the C.S. No. 6 are shown in Fig. 4.

4 Methodological Steps

The following procedure was adopted to achieve the objective of the study:

1. Determination of the hydrographic data for 460 cross sections along the study reach with a spacing of 200 m between sections to construct the mesh of the reach.
2. Collecting the velocities and discharges which were passed during the last years to facilitate the model calibration.
3. Selecting the freely available CCHE2D model and calibrate it using part of the collected data.
4. Verifying the CCHE2D model by determining the reach characteristics such as velocities along the study area and compare the simulation results with the collected field data.
5. Applying the model for the base case having 60 Mm^3/day and for the case of extra discharge of 80 Mm^3/day.
6. Assessment of the results of the extra flow rate case compared to the results of the base case compared to 80 Mm^3/day on river banks and bed levels.
7. All the results were analyzed to propose the proper protection measures for the banks if needed.

5 CCHE2D Model Governing Equations

This study used the hydrodynamic model (CCHE2D) [23] which was based on the solution of Navier–Stokes equations for turbulent flow. The model used the finite volume method for solving the sediment transport equation. The model is applied to determine the changes in the cross sections as a result of passing discharges greater than the current one. This model will be used for calculating and predicting different hydraulic parameters such as average velocity and bed levels (cross sections) at different locations (see Fig. 2).

The governing equations (continuity equation, the momentum equations, and the sediment transport equation) of (CCHE2D) used by the model read:

Continuity equation:

$$\frac{\partial Z}{\partial t}+\frac{\partial (h_u)}{\partial x}+\frac{\partial (h_v)}{\partial y}=0 \tag{1}$$

Momentum equation:

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=-g\frac{\partial Z}{\partial x}+\frac{1}{h}\left[\frac{\partial (hT_{\text{xx}})}{\partial x}+\frac{\partial \left(hT_{\text{xy}}\right)}{\partial y}\right]-\frac{T_{\text{bx}}}{\rho h}+f_{\text{cor}}v \tag{2}$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=-g\frac{\partial Z}{\partial x}+\frac{1}{h}\left[\frac{\partial \left(hT_{\text{yx}}\right)}{\partial x}+\frac{\partial \left(hT_{\text{yy}}\right)}{\partial y}\right]-\frac{T_{\text{by}}}{\rho h}+f_{\text{cor}}u \tag{3}$$

Sediment transport equation:

$$\frac{\partial c_k}{\partial t}+u\frac{\partial c_k}{\partial x}+v\frac{\partial c_k}{\partial y}=\varepsilon_s\left[\frac{\partial^2 c_k}{\partial x^2}+\frac{\partial^2 c_k}{\partial y^2}\right]+\frac{\alpha\omega_{\text{sk}}}{h}(C_{*K}-C_K)+S_C \tag{4}$$

where u and v were the depth-integrated velocity component in the x and y directions; z is the water surface elevation; g is the gravitational acceleration; ρ is water density; h is the local water depth; f_{cor} is the Coriolis parameter; τ_{xx}, τ_{xy}, τ_{yx}, and τ_{yy} are the depth-integrated Reynolds stresses; τ_{bx} and τ_{by} are shear stresses on the bed surface; C_n is the concentration of n-th size class of sediment; S_c is the source term including the derivatives of ε_s and h; z-direction being assigned as the vertical direction along the gravity; ω_{sk} is the settling velocity of the n-th size class of sediment; ε_s is the eddy diffusivity of sediment, $\varepsilon_s = v_s/\sigma_s$; V_t is the eddy viscosity of flow; and σ_s is the turbulent Prandtl–Schmidt number (between 0.50 and 1.0); C_k is the depth averaged concentration, and C_{*k} is the transport capacity of total load.

6 Model Calibration

The required data for the CCHE2D model are geometric and hydrologic data. The hydrologic data is the flow discharges and average velocities along the study area. The geometric data were composed of 90 cross sections, with spacing of 1 km apart. These cross sections were surveyed by HRI in the year 2000 [4–8]. Typical measured velocities and bed levels for two cross sections No. 2 and No. 3 are presented in Figs. 5, 6, 7, and 8 (solid lines). The comparisons between measured (solid line) and computed velocities (dashed line) at the two cross sections are shown in Figs. 5 and 7 for C.S. No. 2 and No. 3, respectively. The corresponding comparison for the bed levels for both sections No. 2 and No. 3 are presented in Figs. 6 and 8. It is clear that the model results are comparable with the measured values. The statistical parameters presented in Table 3 which include the root mean square error (RMSE) and the coefficient of determination between the measured and the simulated confirm the good agreement between the simulated and the measured values.

Fig. 5 Comparison between measured and simulated velocity at C.S. No. (2)

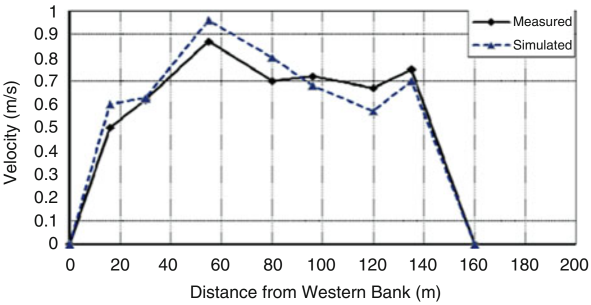
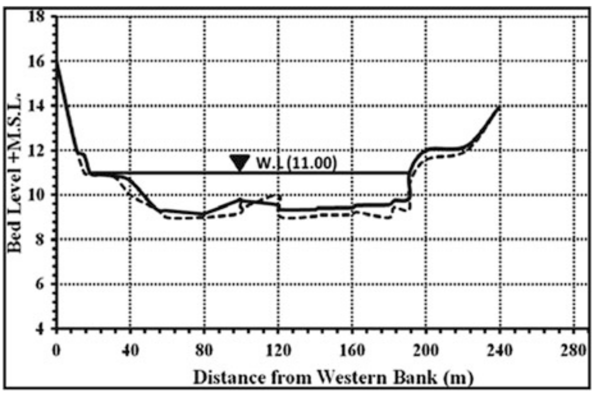


Fig. 6 Comparison between measured and simulated bed levels at C.S. No. (2)



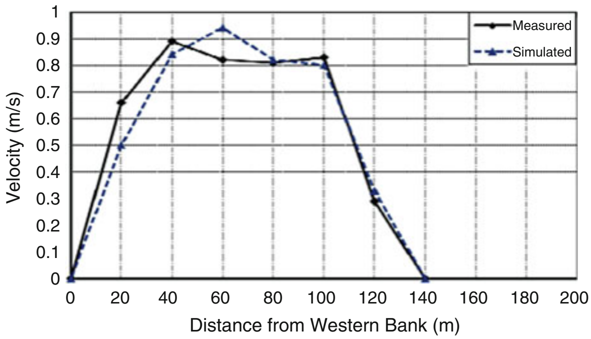


Fig. 7 Comparison between measured and simulated velocity at C.S. No. (3)

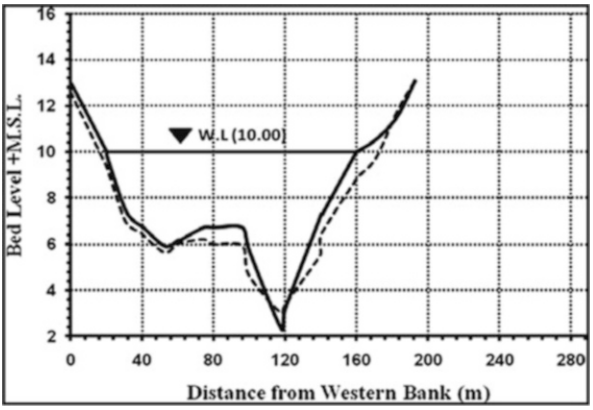


Fig. 8 Comparison between measured and simulated bed levels at C.S. No. (3)

Table 3 Values of the statistical indicators for the velocity simulations compared to the measured values

Parameter	Symbol	Values (%)	Ideal (%)
Root mean square error	RMSE	13.64	0
Correlation coefficient	R	9.10	100

7 Effects of the Increase of the Flow Rate on the Water Way

In the following subsections, the effects of the increase in the flow rate on the width (Sect. 7.1), depth (Sect. 7.2) of Damietta branch at different sections are presented and discussed as long as the effects of the increase in the flow rate on thalweg line level (Sect. 7.3) and on scour and deposition (Sect. 7.4).

7.1 Channel Width Variation

Table 4 and Fig. 9 show that the outer curve of the meandered reach is subjected to erosion and continuous deposition and sedimentation along the inner curve. The C.S. No. 7 indicated high scour potential and deeper bed levels along the West side of the river which reached about 3.0 m above mean sea level. While more deposition is taken place along the East side. The simulated bed level reached a level higher than the measured low water surface level. Consequently, lateral migration of curved river reaches cause several morphological problems that affect the navigation waterway. Maintaining of the navigation path needs dredging of about 3.2 m in the West side.

Table 4 The basic information for the parameters of the cross section from 1 to 10 along Damietta branch [24]

C.S. No.	Discharge (Mm^3/day)				Direction	Diff. area (m^2)	The dredging volume (m^3)
	C.S. area (m^2)		Top width (m)				
	$Q = 60$	$Q = 80$	$Q = 60$	$Q = 80$			
1	241.95	362.11	296	287.2	Shift to left	120.16	2,192.92
2	227.33	266.49	173	169	Shift to left	39.16	293.7
3	501.04	863.05	140	155	Shift to right	362.01	4,887.13
4	580.51	743.9	196.3	189	–	163.39	2,450.85
5	859.52	1,076.9	282.79	275	–	217.4	2,424.01
6	763.06	749.4	198.53	170.44	Shift to left	−13.66	−71.03
7	581.34	750.18	241	238	Shift to left	168.84	337.68
8	779.63	824.75	220	218	–	45.12	72.19
9	1,171.6	1,204.41	154	190	Shift to right	32.81	55.77
10	710.03	832.18	174.4	180	Shift to right	122.15	207.65
Total volume (m^3)							12,921.90

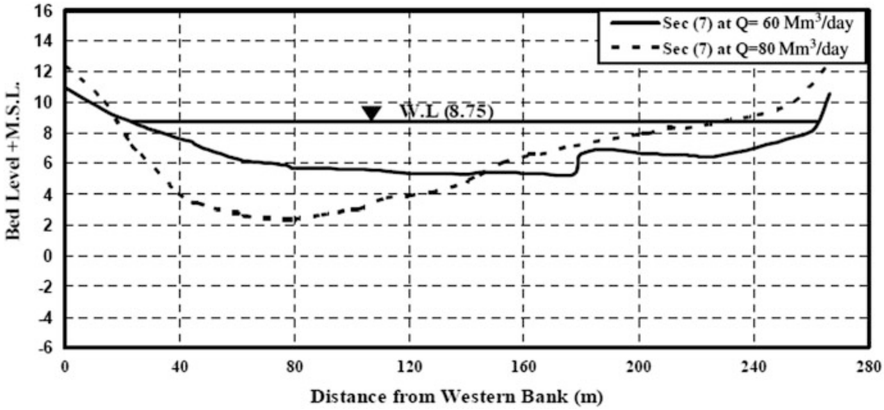


Fig. 9 Comparison of simulated and measured bed levels at $Q = 60$ and 80 Mm^3/day for C.S. No. (7)

The C.S. No.(10) has an island as shown in Fig. 10. This island makes reduction in the flow area. The width of the scour hole and low bed level zone located along the outer curve was enlarged due to the influence of the transverse velocity component of the helical flow current sand caused degradation in this cross section. The bed level near the East bank was lowered to about 2.41 m above the mean sea level and the channel is being narrowed along the downstream. We must dredge about 1.0 m in bottom of the cross section for preparing it to pass expected future discharges 80 Mm^3/day. There are variations in the average top width for cross sections at the study area. The reduction in width leads to acceleration of degradation as shown in C.S. No. (7). Any increasing in degradation will result in instability of the bank and consequently failure may occur which in turn will lead to an increase in the width. This means that the outer curve of the meandered reach is subjected to erosion while deposition will take place along the inner curve.

7.2 *The Variation of Average Depth*

The change in the bed mean depth for the two discharges may be used as an indication of either silting or scouring process. The river meandering variation that took place within the study areas is shown in Table 5 and Fig. 11. At the outer curves of the study reach, there is an increase in the average depth which had taken place due to two factors: (1) The construction of spur dikes at the outer curve that increases the scour depth at the tip. (2) The continuing formation of the island towards the upstream direction as in C.S. No. (9) at km 100.6 downstream EL-Roda Gauge constricts the effective channel width causing the channel to grow deeper.

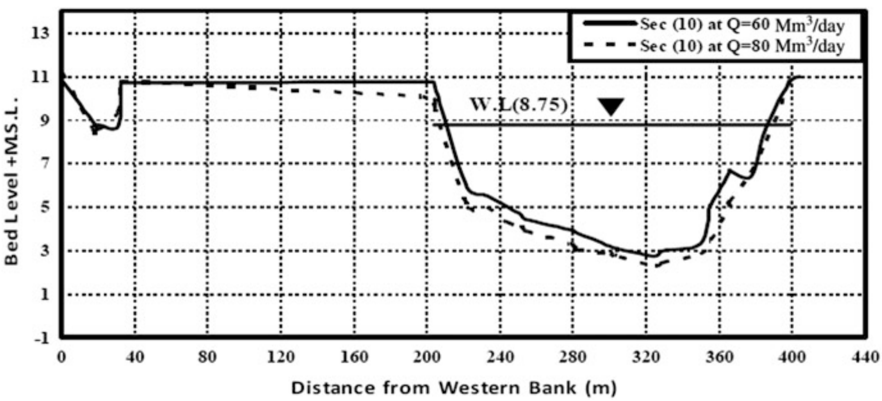


Fig. 10 Comparison of simulated and measured bed levels at $Q = 60$ and 80 Mm^3/day for C.S. No. (10)

Table 5 The average depth at the cross sections from 1 to 10 for Q = 60 Mm^3/day and Q = 80 Mm^3/day

C.S. NO.	Average depth (m) Discharge (Mm^3/day) Q = 60	Q = 80
1	0.817	1.26
2	1.31	1.57
3	3.57	5.56
4	2.95	3.93
5	3.03	3.9
6	3.84	4.68
7	2.41	3.93
8	3.54	4.82
9	7.6	6.7
10	4.07	4.77

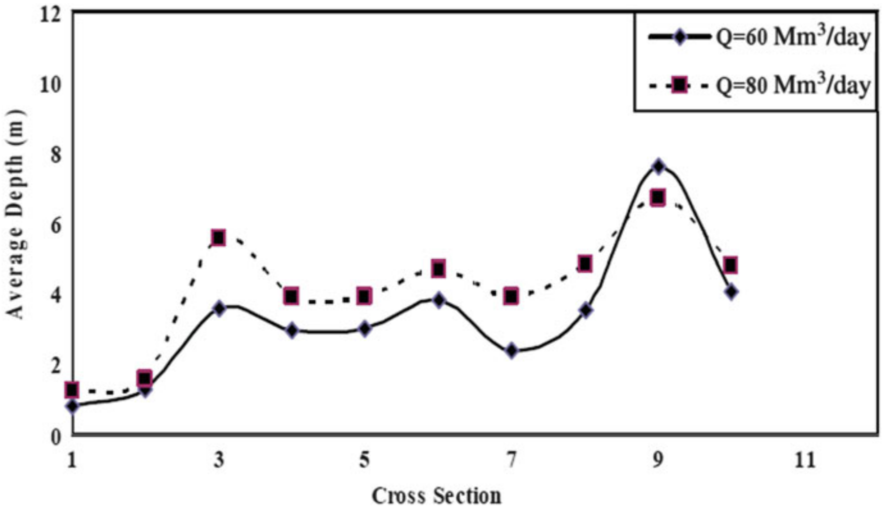


Fig. 11 The average depth at the cross sections from 1 to 10 for Q = 60 Mm^3/day and Q = 80 Mm^3/day along the reach of Damietta branch

7.3 The Variation in Thalweg Line Level

Studying the variation in the thalweg line profile along the study area by measuring the minimum bed levels as indicated in Table 6. The worked out analysis illustrates that the average value of the minimum bed level is lowered from the range between (3.73–2.48 m) to the range between (1.74–0.93 m). The results appeared the morphological changes and the river meandering variation along the study area.

Table 6 The minimum bed level of the cross sections from 1 to 10 along the reach of Damietta branch at $Q = 60$ Mm^3/day and $Q = 80$ Mm^3/day

C.S No.	Min. bed level (m)		Difference	Bed condition
	$Q = 60$	$Q = 80$		
1	9.12	7.75	−1.37	Scour
2	9.16	8.42	−0.74	Scour
3	2.30	3.30	+1.00	Deposition
4	6.81	5.60	−1.21	Scour
5	6.98	6.01	−0.97	Scour
6	0.25	−0.72	−0.97	Scour
7	5.26	−1.15	−6.41	Scour
8	3.47	2.00	−1.47	Scour
9	−1.83	−1.96	−0.13	Scour
10	2.74	2.14	−0.60	Scour

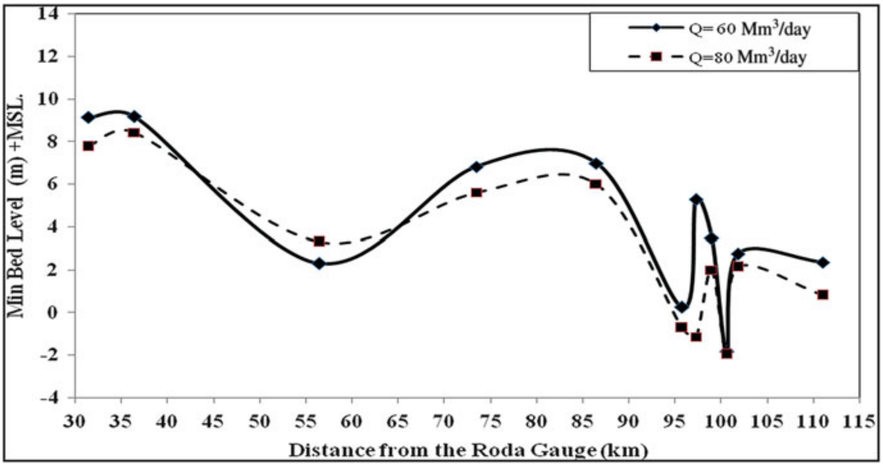


Fig. 12 The minimum bed level at $Q = 60$ Mm^3/day and $Q = 80$ Mm^3/day along the reach of Damietta branch

The comparison between the deepest bed levels corresponding to the previous and future discharges is shown in Fig. 12.

It can be noticed that the average bed level decreases and scour is taken place along the curved meandering zones while the transition zones suffer low deposition. In Table 6 the positive difference value means an increase in the bed level (deposition), while the negative difference values mean a corresponding decrease in the bed level (scour). It can be stated that the average bed level decreases and scour is taken place along the curved meandering zones while low deposition occurred in the transition zones.

7.4 Scour and Deposition

The analysis of simulation results indicated that:

- At C.S. No. (1) the percentage of erosion was approximately 76.11% but the deposition was about 23.8% at the East side.
- At C.S. No. (2) the percentage of erosion was about 57% while the deposition was about 43% at the East side.
- For the C.S. No. (3) and C.S. (4) the percentage of erosion was higher in the whole cross section about 98.7% and little aggradations.
- For C.S. No. (5) there was a gradual widening in the channel cross section, the percentage of erosion was approximately about 79.3% but deposition was about 20.7%.
- At C.S. No. (6) more local scour was accomplished along the West side. Then, the percentage of erosion was about 67.3%. While more deposition is taken place along the East side about 32.7% due to the influence of the cross section by the curvature in the clockwise direction.
- For C.S. No. (7) and C.S. No. (8) the streams tend to be channelized; so that this cross section has lateral migration degradation in the left bank about 80% and very few aggradations in the right bank.
- For the C.S. No. (9) and C.S. No. (10) the deposition zones (islands) increased in width and more local scour occurred with about 87% along the East side of the river, and aggradations were about 13%.
- For the scenario at a discharge equals 80 Mm^3/day, it showed that the bed level at the outer curve increased from1.0 to 3.8 m for safety, and the eroded volume is 12,921.90 m^3.
- The maximum erosion appeared at C.S. No. (3), No. (4), and No. (10), while the maximum deposition occurred at C.S. No. (2) and C.S. No. (6) as shown in Fig. 13.

8 Conclusions

This chapter presented the results of the hydrodynamics simulating of the Nile River (Damietta branch reach) from km 26.5 to km 116.5 downstream EL-Roda Gauge with a total length of 90 km. The calibrated hydrodynamic model (CCHE2D) was used to investigate the impact of increasing the current maximum discharge from 60 Mm^3/day to a maximum expected of 80 Mm^3/day on the morphology of the reach. The following conclusions could be stated:

1. The maximum erosion occurred at C.S. No. (3), C.S. No. (4), and C.S. No. (10), while the maximum deposition was detected at C.S. No. (2) and C.S. No. (6).

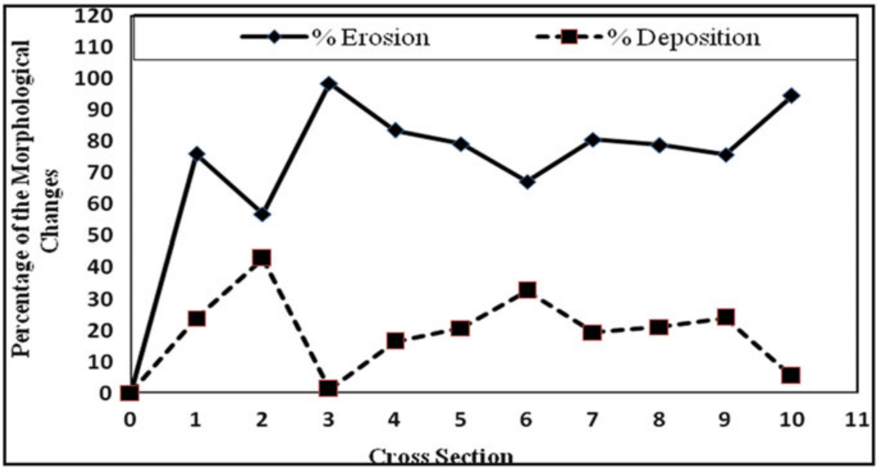


Fig. 13 The percentage of the morphological changes at cross sections from 1 to 10 along the reach of the Damietta branch

2. For the 80 Mm^3/day scenario, the bed level at the outer curve increased from 1.0 to 3.8 m, and the eroded volume was 12,921.90 m^3 compared to the base scenario of 60 Mm^3/day.
3. The widths of the C.S. No. (3), C.S. No. (9), and C.S. No. (10) were increased while the widths of the rest were decreased.
4. The average value of the minimum bed level was lowered from 3.73 m above mean sea level to 0.93 m below mean sea level.

9 Recommendations

Based on the results of the calibrated hydrodynamic model (CCHE2D) in case of releasing an additional discharge of 20 million Mm^3/day in Damietta branch reach, it is recommended to:

1. Dredge about 3.2 m in the West side for the whole study area to sustain safe navigation waterway.
2. Dredge about 1.0 m in bottom of all cross sections near the East bank to increase the ability of Damietta branch to convey high discharges.
3. Continuous monitoring of the cross sections along the reach to measure water levels and velocity pattern and observing the morphological changes in the reach if any.
4. Updating the hydrodynamic simulation for the reach once new updated data are available or a change in the morphology is observed.

Acknowledgment The authors would like to thank the Water Technology Association (WTA) for the permission to republish some materials of the paper "Impact of future discharges on the morphology of Damietta branch" presented at the 15th International Water Technology Conference (IWTC15).

References

1. Gaweesh M, Gasser M (1992) Development of Nile River controls after Aswan High Dam. Annual reports of sedimentation in Aswan High Dam Reservoir, NRI. National Water Research Center, El-Qanater, Egypt
2. Garde RJ (2006) River morphology. New Age International, New Delhi, pp. 1–3
3. Schaepe NJ, Alexander JS, Folz-Donahue K (2016) Effects of streamflows on stream-channel morphology in the eastern Niobrara National Scenic River, Nebraska, 1988–2010. Scientific investigations report 2016–5004. Prepared in cooperation with the National Park Service. U.S. Geological Survey, Reston, VA, USA. doi:10.3133/sir20165004
4. NRI (2006) Study the impact of passing high discharges on Dammita Branch. Cal. Techn. Report no. 46/2005, prepared by A. Fahmy, M. Aziz, and N. Sadek. National Water Research Center, El-Qanater, Egypt
5. NRI (2005) Study operation rules for navigational channel for Damietta Branch. Technical Report no. 28/2005, prepared by A. Fahmy and K. Attia. National Water Research Center, El-Qanater, Egypt
6. NRI (2005) Recent topographic and hydrographic digital maps. Nile Research Institute, National Water Research Center, El-Qanater
7. NRI (2004) Discharge – database. Nile Research Institute, National Water Research Center, El-Qanater
8. HRI (2004) Study Damietta Branch capacity for future discharge. Technical Report no. 107, prepared by A. Blassy, H. Hider, and H. Fathy. Hydraulic Research Institute, National Water Research Center, El-Qanater, Egypt
9. Attia K, El-Said N (2004) Plan form geometry of river meander at Damietta Branch. Sci Bull 39(1):359–379. Faculty of Engineering, Ain Shams University
10. Sadek N, Abdel-Fadil M, El-Barbary Z, Ahmed AF (2009) Morphological change impacts on Damietta Branch capacity. Water Sci 45:75–88
11. Sadek N (2013) Island development impacts on the Nile River morphology. Ain Shams Eng J 4:25–41. doi:10.1016/j.asej.2012.06.006
12. Abdel-Sattar AM, Raslan YM (2014) Predicting morphological changes DS new Naga-Hammadi barrage for extreme Nile flood flows: a Monte Carlo analysis. J Adv Res 5:97–107. doi:10.1016/j.jare.2012.12.004
13. Raslan Y, Salama R (2015) Development of Nile River islands between old Aswan Dam and new Esna barrages. Water Sci 29:77–92. doi:10.1016/j.wsj.2015.03.003
14. Raslan Y (2009) Human impacts on Nile River morphology. In: Fourteenth international water technology conference, Cairo, Egypt. http://www.iwtc.info
15. Attia K, Sadek N (2005) Evaluation of high flow releases effects on Damietta Branch. National Water Research Center, El-Qanater
16. Moustafa A (2005) Nile River morphology expected changes due to abnormal flows. PhD thesis, Faculty of Engineering, Ain Shams University
17. Abdel-Naby M (2006) Study of environmental impact of morphological changes for River Nile in Kasr El-Nile area. MSc thesis, Faculty of Engineering, Ain Shams University
18. Ahmed AA, Fawzi A (2011) Meandering and bank erosion of the River Nile and its environmental impact on the area between Sohag and El-Minia, Egypt. Arab J Geosci 4:1–11

19. Mostafa, DA (2012) Morphological study of the Nile River fourth reach. MSc thesis, Faculty of Engineering, Cairo University, Giza, Egypt
20. Said E, Moussa AM, El-Din MN, Hassan N (2014) Morphological changes of reach two of the Nile River. In: Lehfeldt, Kopmann (eds) Proceedings of ICHE 2014, Hamburg
21. Moussa AM, Aziz MS (2007) Nile River sediment transport simulation. In: Eleventh international water technology conference (IWTC), Sharm El-Sheikh, Egypt, Mar 2007, pp 423–435
22. Zaghloul SS (2006) Effect of Aswan High Dam on the Nile River regime at delta barrages area. In: International sediment initiative conference (ISIC), Khartoum, Sudan, Nov 2006, pp 540–550, 12–15
23. Zhang Y (2005) CCHE2D-GUI–graphical user interface for the CCHE2D model user's manual. Version 2.2, Technical report no. NCCHE-TR-2005-03, The University of Mississippi
24. Negm AM, Abdel-Aziz TM, Nassar M, Fathy I (2011) Prediction of life time span of High Aswan Dam Reservoir using CCHE2D simulation model. In: Fifteenth international water technology conference, IWTC 15–2011, Alexandria, Egypt

Nile River Bathymetry by Satellite Remote Sensing Case Study: Rosetta Branch

Abdelazim Negm, Saleh Mesbah, Tarek Abdelaziz, and Omar Makboul

Abstract Remote sensing (RS) has many applications including bathymetry mapping in shallow water areas. It is considered a useful reconnaissance tool to save time and cost to be used in the preliminary survey. In many regions, natural water stream depth changes because of erosion and sedimentation processes and thus bathymetry must be updated regularly. There are several factors to be taken into account when derived water depth using satellite images in shallow water, especially rivers. These factors include the degree of water transparency, water turbidity, nature of river bottom, and reflections from surrounding areas. This chapter aims to assess the performance of three models to determine the bathymetry of Rosetta branch of the Nile River using Landsat-8. The models are tested on a study area that covers 5 km of Rosetta branch. In-situ measurements were acquired by the Nile Research Institute and data are registered to the satellite imagery spatial reference. Landsat-8 image bands are first pre-processed to carry out atmospheric corrections and to mask out land areas and remove scattering and sun specular effects. The tested models are the generalized linear model (GLM), 3rd order polynomial, and the artificial neural networks (ANN). The three models are applied to the pre-processed Landsat-8 image to derive the Rosetta branch bathymetry at the study area. Results showed that the ANN model results are more accurate than both GLM and nonlinear 3rd order polynomial models. However, the results of the three models are not well satisfactory as the root mean square error (RMSE) is

A. Negm (✉)
Faculty of Engineering, Zagazig University, Zagazig 44519, Egypt
e-mail: amnegm85@yahoo.com; amnegm@zu.edu.eg

S. Mesbah and O. Makboul
Arab Academy for Science, Technology and Maritime Transport, Alexandria, Egypt
e-mail: Saleh.mesbeh@gmail.com; Omarm526@gmail.com

T. Abdelaziz
Nile Research Institute, NWRC, MWRI, El Qanater 13621, Egypt
e-mail: aziztm@hotmail.com

A.M. Negm (ed.), *The Nile River*,
Hdb Env Chem (2017) 56: 259–274, DOI 10.1007/698_2017_17,

about 2 m. The high turbidity of the Rosetta water is one of the main reasons affecting the performance of the three models.

Keywords Bathymetry, Nile River, Remote sensing, Rosetta branch

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1 Introduction

The detection of bathymetry using satellite RS becomes an essential in many fields. The bathymetry is a branch of the hydrographic surveying that deals with the measurement of the depth of bodies in water to determine underwater topography [1]. Bathymetric information is important to coastal and marine planning and management, nautical navigation, and scientific studies of marine environments. Recently, bathymetric surveying of shallow water has been mainly based on conventional ship-borne echo sounding operations. However, this technique demands cost and time, particularly in shallow waters, where a dense network of measured points is required [2]. Single beam echo sounder (SBES) on survey vessel can acquire single point depths along sparsely surveying scan lines up to 500 m depths. Multi-beam echo sounder (MBES) improves the scanning with wide swath coverage below the vessel scan line resulting better resolution of the resulting sounding [3] with full bottom coverage and depth accuracy up to 1 cm. These techniques are relatively time consuming compared to the use of RS one.

During the last decades, RS technology is developed rapidly. This provided a new technique for bathymetry. Bathymetry by RS has a lower precision, lower cost, short-period, and wide coverage. The theory behind all bathymetric mapping using optical RS is that different wavelengths of light penetrate water with varying degrees. When the light passes through water, it becomes attenuated by interaction with water column according to Beer's law [4]. Therefore, the light is reflected from the seabed in shallow water which appears bright as a less amount of light has been absorbed. Conversely, deep areas appear darker [5]. All the radiance and irradiances are decreased approximately exponentially with depth after atmospheric and water column effects have been removed, at least when far enough below the surface due to absorption and scattering properties of the water column according to Beer's law [6]. Optical RS can be implemented for bathymetry derivation by using two methods: analytical modeling and empirical modeling [7]. Analytical modeling of bathymetry is based on the propagation of light in water. For the establishment of this model, a number of optical properties of water such as the attenuation coefficient and backscattering are required as inputs [8]. In empirical modeling, the relationship between the remotely sensed radiance or reflectance of a water body and the depth at sampled locations are established empirically without consideration to how the light is transmitted in water [9]. Lyzenga developed the first empirical methods for estimating bathymetry based on Lambert–Beer law of attenuation [10], then the satellite has experienced significant evolution in both spatial and spectral resolutions. Lyzenga [11] developed a technique to derive bathymetry using a log–linear relationship between corrected image reflectance values and water depths after removing the sun-glint and water column effect by subtracting the minimum spectral radiance of deep water area from bands [12]. The resulted differences in reflectance values will be due to changes in water depths. Stumpf et al. [13] developed a technique depending on the ratio of different attenuation rates between wavebands to determine depth. The band with a higher absorption rate will decrease proportionally faster than the band with a lower absorption rate. The change in the ratio between the bands will affect the higher absorption band more with increasing depth therefore, as depth increases the change in ratio between the two bands will be affected more by depth. Although this theory needs less parameters and less affected with bottom type, it does not have sound physical foundation and needs pre-coefficients selected via trial and error by the user. Some researchers try to derive bathymetry using empirical modeling such as [14]. Ceyhun and Yalçın [14] used artificial neural network (ANN) to derive bathymetric maps in shallow waters via RS images and sample depth measurements. Corucci [15] used neuro-fuzzy technique applied to two Quick bird images of the same area, acquired in different years and meteorological conditions. Su et al. [3] tried to calibrate the parameters for the nonlinear inversion model proposed by Stumpf automatically using the Levenberg–Marquardt optimization algorithm. Sari et al. [16] used the principal component analysis (PCA) for detecting water depths from satellite images.

The accuracy of the retrieved bathymetry from water depends on several limitations and is called practical limitations [17]. Practical limitations arising from sensor specifications such as turbidity and variations in water color may confuse bathymetry, RS which generally provides geomorphologic rather than biological information, disparity between dates of image, and field work complicates image interpretation and spatial and spectral resolution which are too coarse [18]. Water turbidity is an important factor affecting the accuracy. It obstructs the path of electromagnetic radiation (EMR). Reflectance from suspended particles becomes confused with bottom reflectance. Water of different turbidity levels scatters the incoming radiation differently [7]. The total signal received at the satellite altitude is dominated by reflectance contributed through atmospheric scattering processes. Therefore, it is advisable to correct for atmospheric effects to retrieve any quantitative information for surface from the image [19].

The methodology proposed in this chapter uses the generalized linear model (GLM), the nonlinear 3rd order polynomial, and the artificial neural network (ANN) to estimate water depth from Landsat-8 satellite image in shallow water after removing atmosphere and sun-glint corrections and their logarithms as independent variable. Applying atmosphere and sun-glint corrections reduce their influence on the detected depths. The methodology is applied in Rosetta branch of the Nile River that represents turbidity water located in urban area.

2 The Study Area and Data Collection

The study area is a part of Rosetta branch of Nile River, Rosetta branch is located in El-Buhayra Governorate, Egypt. The study area extends from 149 to 154 km (see Fig. 1). In general, the average depth of water in Rosetta branch ranges from 2 to 4 m which represents shallow water area. However, the depth of water in the study area ranges from 0.5 to 18 m. The depth of 18 m is not dominant but some places suffer from a deep scour hole. Table 1 presents the descriptive statistics to the in-situ measurements of the study area. The maximum width between two shores is 380 m and the less view is 170 m. The study area is surrounded by agricultural and urban areas. In-situ measurements were acquitted from Ministry of Water Resources and Irrigation, Nile Research Center, Nile Research Institute. In-situ measurement is implemented in October 2009. In-situ measurements had been done using modern and accurate equipment in order to obtain accurate water depth and bottom contour information. In-situ measurements had been executed by Egyptian Survey Authority February–August 2003. The used projection is Transverse Mercator and projection ellipsoid is Helmret 1906. Vertical datum is mean sea level at Alexandria 1906.

3 Materials and Methods

3.1 Satellite Image and Sensor Data

Landsat-8 collects image data in 11 spectral bands with a 30 m spatial resolution (see Fig. 2). The bands used for detecting bathymetry in this study are costal/aerosol (0.435–0.451 μm), blue (0.452–0.512 μm), green (0.533–0.590 μm), red (0.636–0.673 μm), and near-infrared (NIR) (0.851–0.879 μm) [20]. The Landsat-8 data used in this study are collected on 11-9-2013 with an average cloud cover less than 10%.

Table 1 Descriptive statistics to the in-situ measurements (dimensions in meter)

Mean	STD	Minimum	Maximum	Range	Median	Mode
3.8803	2.898	0.5	18	16.5	3	2

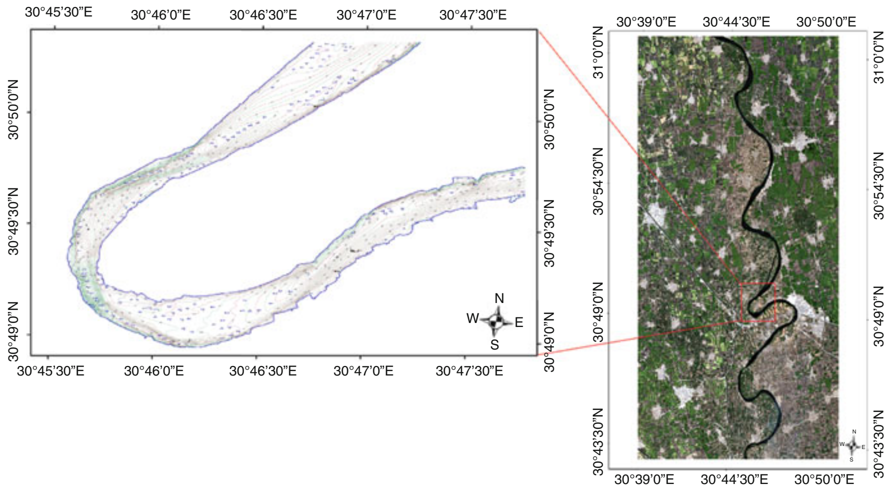

Fig. 1 Rosetta branch of the River Nile and the location of the case study (points on left-hand side plot indicate the location of actual measurements)

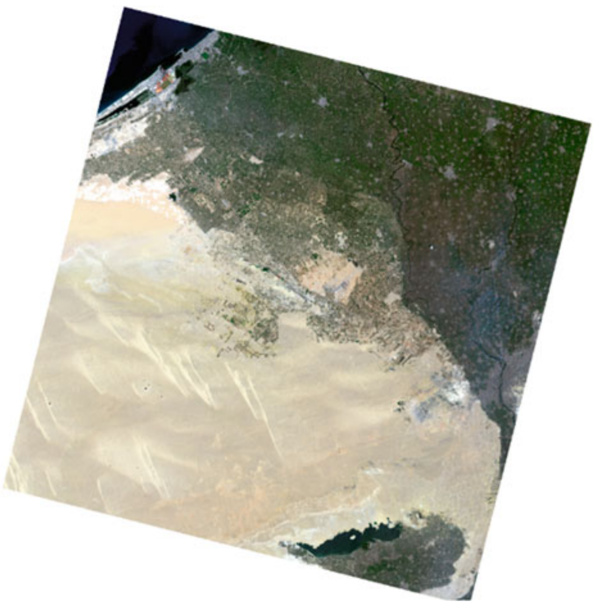

Fig. 2 Landsat-8 satellite image. ROW 39/PATH 177

3.2 Imagery Data Pre-processing

Satellite images are affected by a variety of environmental factors such as atmosphere and sun specular. It needs pre-corrections to avoid the influence of the inversion depth. The pre-processing has great effect on improving the precision of inversion depth. The radiometric corrected pixel values are firstly converted to spectral reflectance. Second, two corrections steps are applied to the image: atmospheric correction and sun-glint correction. The sequence of applying these two corrections is arbitrary. Some researchers started with atmospheric correction followed by sun-glint correction while others reverse this procedure [21].

3.2.1 Converting to Radiance

Convert the digital number (DN) to the spectral radiance at the aperture (L_λ) is measured in (watts/meter squared × ster × μm) using the gain and bias information of sensor bands as indicated by Eq. (1):

$$L_\lambda = \mathrm{ML} \times Q\mathrm{cal} + \mathrm{AL} \tag{1}$$

where ML is band-specific multiplicative rescaling factor (radiance_mult_band_x) or rescaling gain factor (Gain) from Landsat metadata files, Qcal is calibrated standard product pixel values (DN), and AL is band-specific additive rescaling factor (radiance_add_band_x) or rescaling bias factor (Bias) from Landsat metadata file [22].

3.2.2 Applying Atmospheric Correction

The solar radiation passes through the atmosphere before collected by the sensor. Therefore images are affected by several factors such as water vapor and distribution of aerosols (visibility). In this chapter, the FLASSH model in ENVI software is used to correct the atmospheric effect that applied to the solar wavelength. FLAASH normally retrieves aerosol and water vapor information from the image, providing well-adjusted input for the atmospheric correction. FLAASH starts from a standard equation for spectral radiance at a sensor pixel according to Eq. (2) [23].

$$L = \left(\frac{A\rho}{1-\rho_\mathrm{e}^\mathrm{s}}\right) + \left(\frac{B\rho_\mathrm{e}}{1-\rho_\mathrm{e}^\mathrm{s}}\right) + L_\mathrm{a} \tag{2}$$

Where ρ is the pixel surface reflectance, ρ_e is an average surface reflectance for the pixel and a surrounding region, s is the spherical albedo of the atmosphere, and L_a is the radiance back scattered by the atmosphere. A and B are coefficients that depend on atmospheric and geometric conditions but not on the surface. Moreover, A, B, S, and L_a are depending on water vapor amount. The input files must contain calibrated radiance values and converted to BSQ or BIP format before the atmospheric correction. In addition to the image file to be corrected, FLAASH also needs information on the geographical center location of the image and the time it was captured. This information can't be retrieved automatically from the data file, but must be entered by the user. An atmospheric model must be selected depending on climate (latitude and time of year). Urban aerosol model is selected depending on the expected type of aerosols and visibility present.

3.2.3 Land Masking

When extracting aquatic information, it is useful to eliminate all upland and terrestrial features. Thus, all upland features were masked out of the image. The "land-mask" restricts the spectral range to aquatic features and allows for detailed feature discrimination. Reflectance values of the NIR band were used to prepare the mask which was subsequently applied to all the bands [19]. The threshold value for land/water was calculated to separate water area.

3.2.4 Applying Sun-Glint Correction

Specular reflection of solar radiation, known as sun glint must be removed for accurate benthic habitat classification. Hochberg [24] provided a method to remove sun glint by using the brightness of near-infrared (NIR) band. Hedley [25] proposed revised method depending on Hochberg assumption that based on the linear relationship between NIR and visible bands using linear regression. By using linear regression of NIR brightness (x-axis) against the visible band brightness (y-axis), this would be homogeneous if not for the presence of sun glint (deep water). The slope of the regression is then used to predict the brightness in the visible band by using Eq. (3). The minimum sample size required is two pixels.

$$R_i' = R_i - b_i(R_{\mathrm{NIR}} - \mathrm{MIN}_{\mathrm{NIR}}) \quad (3)$$

Where R_i' is the sun-glint corrected pixel brightness in band i, b_i is the product of regression slope, R_{NIR} is the corresponding pixel value in NIR band, and $\mathrm{MIN}_{\mathrm{NIR}}$ is the min NIR value existing in the sample.

3.3 Methods

3.3.1 Artificial Neural Network Model

Artificial neural networks (ANN) are models of the brain's cognitive process. The brain has multi-processor architecture that is highly interconnected and it can be described as parallel distributed processing [26]. ANN information processing system consists of a large number of highly connected processing elements like neurons tied together with weighted connection like synapses [27]. Figure 3 presents an ANN with typical architecture. The ANN can model highly nonlinear function and can present with new unseen data. It has the ability to handle the complex nonlinear mapping relationship with good generalization. It can be used for many applications as image processing, environmental science, medicine, and molecular biology [28].

A multilayer perceptron technique is used. This consists of a system of simple interconnected neurons or nodes. The nodes are connected weights output signals which are function of the sum of the inputs as given by Eq. (4).

$$\mathrm{net}_j = \sum_{l=1}^{m} (W_{\mathrm{L},i} \times O_{\mathrm{L}}) + b_j \tag{4}$$

Where $W_{\mathrm{L},\ j}$ are the network weights between the inputs node and hidden layer nodes, O_{L} is the output of the first layer which represents the element of the input vectors for the input layer, and b_j are the biases [14]. The values of the nodes in the hidden layer are modified by nonlinear activation sigmoid function which is used

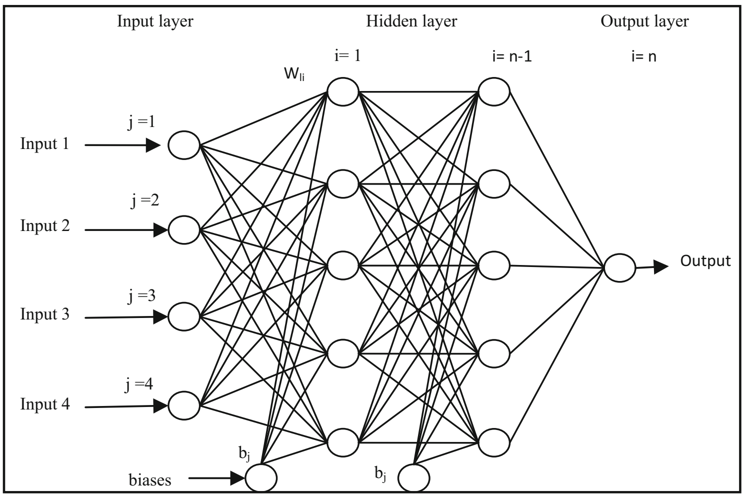

Fig. 3 Typical ANN architecture

for transferring the net input net_j into the node output O_L as its easily computed derivative and commonly use Eq. (5).

$$f(\text{net}_j) = \frac{1}{1 + \exp(-\text{net}_j)} \tag{5}$$

A multilayer perceptron has the ability to learn through training. This training is the procedure by which the values for the individual weight are determined such that the built relationship via the network is accurately resolved. Training requires a set of training data which consists of series of randomized input and associated output vectors [29]. The objective of training is to find the combination of weights which result in the smallest residuals.

Error back-propagation learning algorithm is used for training data in multilayer perceptron network. It was initialized by network weight with small random values. Then, propagate the input vector through the network to obtain an output then calculate an error by comparing actual output to the desired output. After that, propagate error signal back through the network and adjust weights to minimize the overall error. Figure 4 summarizes this procedure. This procedure is repeated until an acceptable RMSE is reached [30]. The RMSE is given by Eq. (6).

$$\text{RMSE} = \sum_{i=1}^{N} \sqrt{\frac{(d_m - d_e)^2}{N}} \tag{6}$$

Where N is the numbers of observations, d_m is actual output (measured) or target, and d_e is the desired output. Levenberg–Marquardt is used (in this study) for updating weight and bias values. It is fast and has stable convergence [31]. The algorithm is given by Eq. (7).

$$X_{K+1} = X_K + \left[J^T J + \mu I\right]^{-1} J^{T_{\xi_K}} \tag{7}$$

Where X_K is a vector of the current weights and biases, ζ and JJ are the vector and Jacobean matrix of the network errors, respectively, μ is a scalar which indicates calculation speed of the Jacobean matrix, K is iteration number, I is the unit matrix, and T indicates transposition.

3.3.2 Generalized Linear Model

The GLM represents the least-squares fit of the link of the response to the data. GLM links a linear combination of non-random explanatory variables X as example image bands to dependent random variable Y as instance the water depths values [21]. It fits a nonlinear function of the mean of the observed variable $g\{\mu(Y)\}$, the link function to a linear predictor of the explanatory variables, taking into account the statistical distribution of both types of variables as given by Eq. (8).

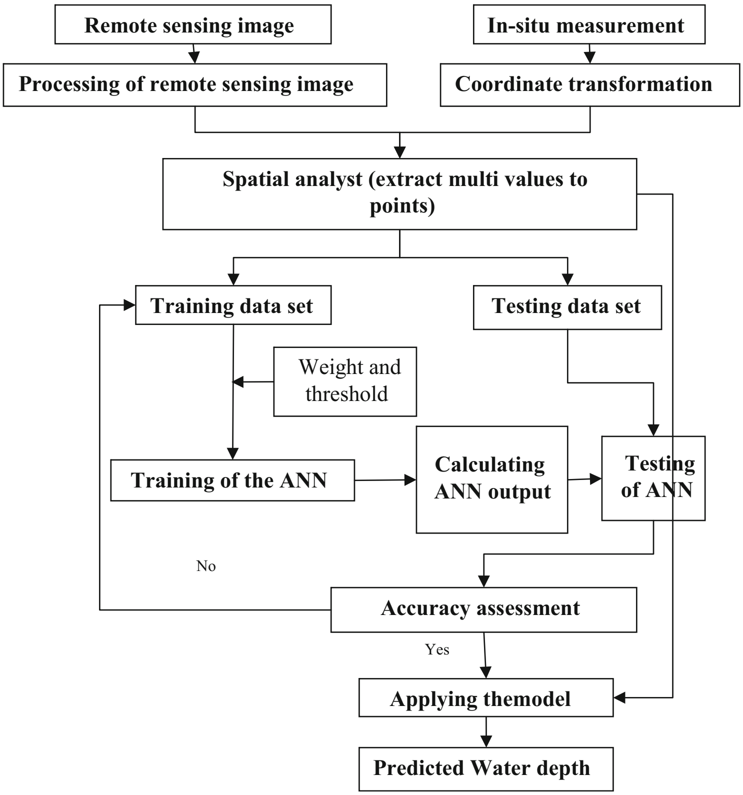

Fig. 4 Methodology of water depth inversion using ANN

$$g\{\mu(Y)\} = \beta_{\circ} + \sum_{i} \beta iXi + \sum_{ij} \beta ijXiXj \quad (8)$$

Where $\beta_{\circ}$, βi, and βij are coefficients and Xi and Xj are variables combinations.

3.3.3 Third Order Polynomial

The nonlinear 3rd order polynomial has the form of Eq. (9).

$$ax3 + bx2 + cx + d = y \quad (9)$$

Where $a \neq 0$ the equation must have the term in x^3 or it would not be cubic. All of b, c, and d can be zero.

3.3.4 Depth Modeling and Simulation

Preparation of models input and determination of model architecture and parameters are two important steps to model water depth in shallow water. Three models will be developed including the ANN, the GLM, and the 3rd order polynomial. Models inputs are the reflectance from spectral bands. The in-situ measurements are pre-processed. The in-situ measurements transformed from projection ellipsoid Helmert 1906 into the same coordinate system of image acquisition (map projection = UTM, datum = WGS84, and ellipsoid = WGS 84). Model parameters are obtained as a result of training and testing processes. The methodology is summarized according to the flowchart presented in Fig. 5. The image is first filtered to discard the atmospheric effect. Secondly, water reflectance values are isolated from the land. Thirdly, sun specular effect is removed to decrease noise and scattering

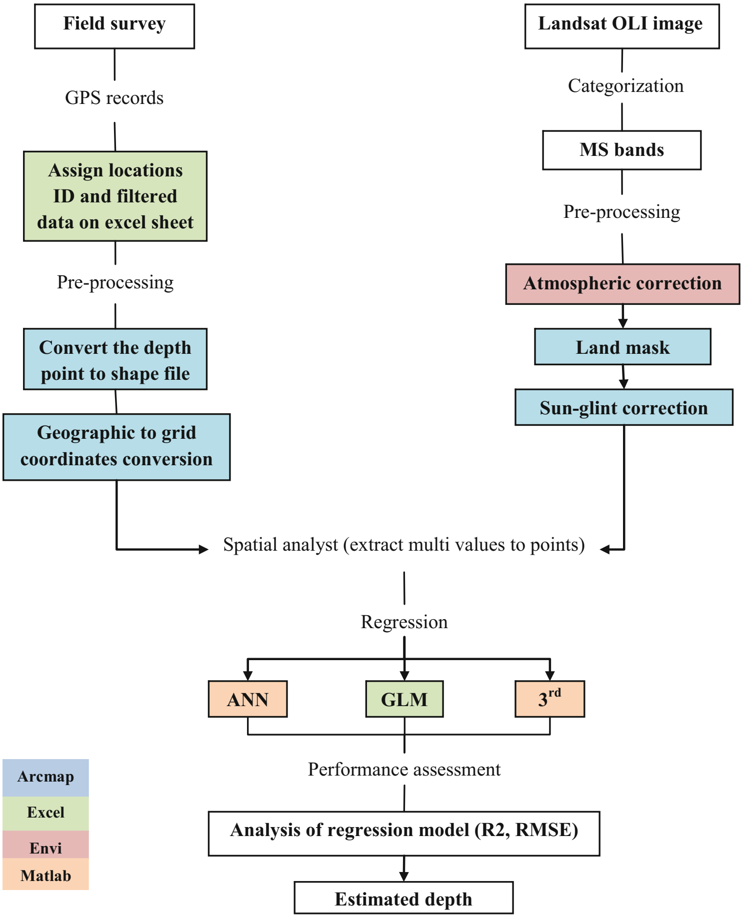

Fig. 5 Methodological flowchart

effects on the input image. The reflectance values corresponding to the point, where there are available depth measurements, are extracted from multispectral images for usage bands. The in-situ measurements are 239,000 point and bathymetric range between 0.5 and 18 m. Due to the large number and structure of the data used in bathymetric mapping, the average reflectance values corresponding to each depth are taken in the training phase to calculate the model parameter. The derived equation is applied at 240 points, so as to facilitate the graph for both the GLM and the 3rd order polynomial models. For the ANN, the depth estimations obtained for the training, validation, and testing data sets for all in-situ data (239,000) where 70% of data set for training, 15% for testing, and 15% for validation. The data are randomized before dividing them into three sets. Once the model inputs are prepared, model architecture and parameters can be readily determined.

4 Results

The ANN, the GLM, and the third (3rd) order polynomial are applied to pre-processed Landsat-8 multispectral image.

The nonlinear 3rd order polynomial correlation was applied to the green band logarithm (L_G) and water depth values (z) in the form:

$$z = 1058 \times L_G^3 - 4769 \times L_G^2 + 7236 \times L_G - 3627 \quad (10)$$

The statistical measures R^2 and RMSE for training and testing data are shown in Table 2 while the 3rd order fitted continuous model for the polynomial is shown in Fig. 6.

The generalized linear model (GLM) is applied to combination of coastal (L_c), blue (L_B), green (L_G) and red (L_R) logarithms. These bands are linked to the water depths values as follows:

$$z = -83.765 - 21.0232 \times L_C - 48.532 \times L_B + 110.775 \times L_G + 17.937 \times L_R \quad (11)$$

The statistical measures R^2 and RMSE for training and testing data are shown in Table 3 and the GLM fitted continuous model is shown in Fig. 7.

For ANN, the multilayer perceptron back propagation model with Levenberg–Marquardt training algorithm learning is used to train the network constituted. Initial weights are given randomly. The neural networks are determined after many experiments with trial and error so that the numbers of nodes and layers as

Table 2 The 3rd order polynomial depth estimation performance

	R^2		RMSE	
Band	Train	Test	Train	Test
3	0.438	0.103	3.858	3.066

Table 3 The GLM depth estimation performance

	R^2		RMSE	
Band	Train	Test	Train	Test
1, 2, 3, 4	0.464	0.0525	4.012	4.094

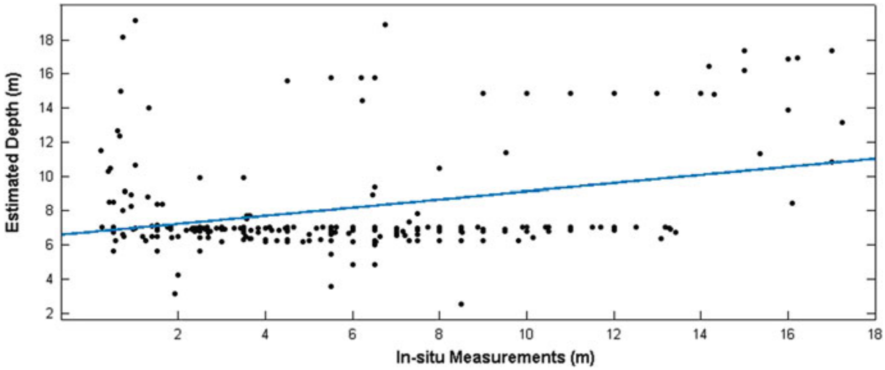

Fig. 6 The 3rd order polynomial continuous fitted model. Line represents the fitted continuous model while depths are represented as points

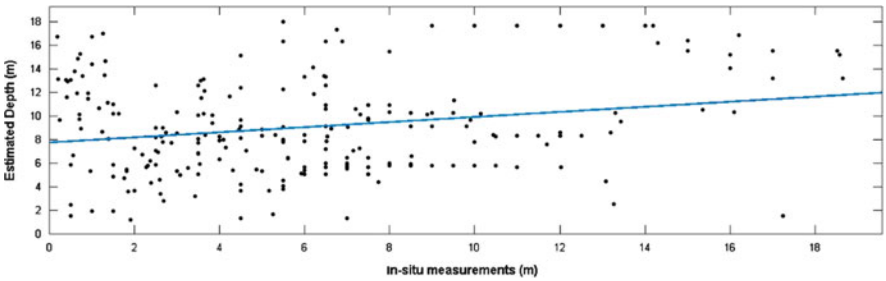

Fig. 7 The GLM continuous fitted model. Line represents the fitted continuous model while depths are represented as points

well as the RMSE between calculated and measured depths are minimum. The log-sigmoid activation function was used as a transfer function. The four multi-spectral bands (coastal, blue, green, and red) are used as an input layer and in-situ measurements as target. The R^2 and RMSE for training, testing, and validation data are shown in Table 4.

Table 4 ANN depth estimation performance

Band	R^2			RMSE		
	Train	Test	Valid	Train	Test	Valid
1, 2, 3, 4 (4-10-10-1)	0.512	0.507	0.512	2.024	2.029	2.019

5 Discussion

The procedure to obtain the satellite bathymetry included water separation, glint, and atmospheric correction. The GLM and the 3rd order polynomial did not provide reliable depth estimation in the study area as shown by the coefficients of determination R^2 (that represent the extent of the variability in the known depth explained by transformed bands). The correlation between derived depth and in-situ depth values obtained for bands combinations is summarized in Tables 1 and 2. The presented values show poor correlation for green band ($R = 0.320$) using the 3rd order polynomial for testing data set and ($R = 0.228$) for 4 bands combination using GLM.

The nonlinear ANN model enables the proposed methodology to produce more accurate estimations than classical regressive methods. Table 3 shows the value of the RMSE and R^2. The water depth derived from ANN has high correlation coefficient ($R = 0.712$) and lower RMSE compared to the GLM and the 3rd order polynomial. However, the results of the three model are not satisfactory. This may be explained by the fact that Rosetta branch of Nile River is turbid water due to the deteriorated water quality of the branch. The water turbidity and pollution are considered the main causes of influences on the accuracy. “There are serious problems of contamination found in the Rosetta branch. This is due to the increase in waste discharge along drains into the Rosetta branch” [32]. Rosetta branch water quality was affected by the wastes of several industrial companies at Kafr El-Zayat city which produced more than 40 kinds of chemical products and their industrial outfalls are El-Mobidat [33]. Also, remarkably influenced by wastewater discharge (Agricultural and sewage wastes) from drains located on its sides regarding both physicochemical and bacteriological characteristics [34]. Also, Landsat-8 has lower resolution 30 m × 30 m and fewer pixels therefore there is no good possibility to estimate water depths for regions smaller than 900 m^2. However, the precise depth measurements may be obtained if high resolution image is used in clear water. Artificial neural networks can be effectively used for bathymetric modeling whenever the water quality is good [27].

6 Conclusion and Recommendation

In this chapter, the proposed methodology used bands corrected from atmospheric and sun-glint errors which influence the bathymetry and their logarithms as input values. The used models are trained and tested by data collected via Echo-Sounder by the Nile Research Institute. Results show that the optical bathymetry based on the empirical models cannot produce accurate estimation of the water depth even in water shallower than 20 m in depth when its quality is deteriorated (turbid water). The obtained RMSE is about 2–4 m which is too much compared to the actual depth of water in the branch. The three tested models produce unsatisfactory water depths mainly due to water turbidity and partially due to image spatial resolution and limited area coverage. The root mean square error (RMSE) is 4.09 and 3.06 m for the GLM and the 3rd order polynomial, respectively. The ANN has a lower RMSE of 2.02 m. It is recommended to isolate the effect of turbidity of water to obtain a higher accuracy. Also, in such areas, high resolution images are recommended.

References

1. Raj A, Sabu P (2013) Shallow water bathymetry using log-linear inversion technique: a case study at Vizhinjam. Int J Innovat Res Sci Eng Technol 2(1):223–230
2. Pattanaik A, Sahu K, Bhutiyani MR (2015) Estimation of shallow water bathymetry using IRS-multispectral imagery of Odisha Coast India. Aquat Procedia 4(0):173–181
3. Su H, Liu H, Heyman WD (2008) Automated derivation of bathymetric information from multi-spectral satellite imagery using a non-linear inversion model. Mar Geod 31:281–298
4. Ehses JS, Rooney JJ (2015) Depth derivation using multispectral WorldView-2 satellite imagery. Civ Environ Eng 24–46 https://www.pifsc.noaa.gov/library/pubs/tech/NOAA_Tech_Memo_PIFSC_46.pdf
5. Melsheimer C, Chin LS (2001) Extracting bathymetry from multi-temporal SPOT images. Asian Conf Remote Sens 58(12):37–42
6. Camacho M (2006) Depth analysis of midway atoll using QuickBird multi-spectral imaging over variable substrates. Master's thesis, Navel Postgraduate School, Monterey, CA
7. Gao J (2009) Bathymetric mapping by means of remote sensing: methods, accuracy and limitations. Prog Phys Geogr 33(1):103–116
8. Jawak SD, Luis AJ (2016) High-resolution multispectral satellite imagery for extracting bathymetric information of Antarctic shallow lakes. Proceeding of the international society for optical engineering. p 987819
9. Doxani G, Papadopoulou M, Lafazani P, Pikridas C (2012) Shallow-water bathymetry over variable bottom types using multispectral Worldview-2 image. *ISPRS*—international archives of the photogrammetry, remote sensing and spatial information sciences. XXXIX (September), pp 159–164
10. Lyzenga DR (1978) Passive remote sensing techniques for mapping water depth and bottom features. Appl Opt 17:379–383
11. Lyzenga DR (1985) Shallow-water bathymetry using combined lidar and passive multispectral scanner data. Int J Remote Sens 6(1):115–125
12. Lyzenga DR (1981) Remote sensing of bottom reflectance and water attenuation parameters in shallow water using aircraft and Landsat data. Int J Remote Sens 2(1):71–82

13. Stumpf RP, Holderied K, Sinclair M (2003) Determination of water depth with high-resolution satellite imagery over variable bottom types. Limonol Oceanogr 48(1_part_2):547–556
14. Ceyhun Ö, Yalçın A (2010) Remote sensing of water depths in shallow waters via artificial neural networks. Estuar Coast Shelf Sci 89(1):89–96
15. Corucci L (2011) Approaching bathymetry estimation from high resolution multispectral satellite images using a neuro-fuzzy technique. J Appl Remote Sens 5(1):053515
16. Sari E, Gholamalifard M, Abkar A, Naimi B (2013) Principal components analysis (PCA) in Southern Caspian Sea. Int J Environ 7(4):877–886
17. Green EP, Mumby PJ, Edwards AJ, Clark C (1996) A review of remote sensing for the assessment and management of tropical coastal resources. Coast Manag 24(1):1–40
18. Green EP, Mumby PJ, Edwards AJ, Claek CD (2000) Remote senseing handbook tropical coastal management. Coastal management sourcebook 3, vol X. UNESCO, Paris, p 316
19. Mishra DR, Narumalani S, Rundquist D, Lawson M (2005) Characterizing the vertical diffuse attenuation coefficient for downwelling irradiance in coastal waters: implications for water penetration by high resolution satellite data. ISPRS J Photogramm Remote Sens 60(1):48–64
20. USGS (2015) Landsat 8 (L8) data users handbook. Department of Interior, U.S. Geological Survey
21. Mohamed H, Negm A, Zahran M, Saavedra OC (2016) Bathymetry determination from high resolution satellite imagery using ensemble learning algorithms in Shallow Lakes: case study El-Burullus Lake. Int J Environ Sci Dev 7(4):295–301
22. Chander G, Markham BL, Helder DL (2009) Remote sensing of environment summary of current radiometric calibration coefficients for Landsat MSS, TM, ETM +, and EO-1 ALI sensors. Remote Sens Environ 113(5):893–903
23. ENVI (2009) ENVI atmospheric correction module: QUAC and FLAASH User's guide. ITT Visual Information Solutions
24. Hochberg EJ, Andréfouët S, Tyler MR (2003) Sea surface correction of high spatial resolution ikonos images to improve bottom mapping in near-shore environments. IEEE Tran Geosci Remote Sens 41(7-PART II):1724–1729
25. Hedley JD, Harborne AR, Mumby PJ (2005) Technical note: simple and robust removal of sun glint for mapping shallow water benthos. Int J Remote Sens 26(10):2107–2112
26. Graupe D (2013) Principles of artificial neural networks, 3rd edn. World Scientific Publishing Co. Pte. Ltd, Singapore
27. Mohamed H, Negm A, Zahran M, Saavedra OC (2015) Assessment of artificial neural network for bathymetry estimation using High Resolution Satellite imagery in Shallow Lakes: case study El Burullus Lake. In: International water technology conference. pp 12–14
28. Walker JM (2015) Artificial neural networks, vol 1260, 2nd edn. Springer, New York
29. Yanjiao W, Peiqun Z, Wenjie D, Ying Z (2007) Study on remote sensing of water depths based on BP artificial neural network. Mar Sci Bull 9(1):26–35
30. Gardner MW, Dorling SR (1998) Artificial neural networks (the multilayer perceptron)—a review of applications in the atmospheric sciences. Atmos Environ 32(14–15):2627–2636
31. Yu H, Wilamowski BM (2011) Levenberg–Marquardt training, chapter 12. In: Intelligent systems. Industrial electronics handbook, vol. 5, 2nd edn. CRC Press, p 12–1 to 12–15
32. Elhaddad E, Al-Zyoud S (2017) The quality assessment of pollution of Rosetta branch, Nile River, Egypt. Arab J Geosci 10:97. doi:10.1007/s12517-017-2870-y
33. Alawy AE, El-tras WF, Khater DF, El Raiy HR (2015) Impact of industrial wastewater on water and fish quality of Nile River in Kafr El-Zayat, Egypt. BENHA Vet Med J 78:87
34. Ezzat SM, Mahdy HM, Abo-State MA, Abd El Shakour EH, El-Banhnasawy MA (2012) Water quality assessment of River Nile at Rosetta Branch: impact of drains discharge. Middle-East J Sci Res 12(4):413–423

Toward a Dynamic Stability of Coastal Zone at Rosetta Promontory, Egypt

Ali Masria, Abdelazim Negm, and Moheb Iskander

Abstract Rosetta promontory, Egypt, experiences coastal problems such as severe erosion along the shoreline and siltation problem at the outlet. This is due to the lack of water and sediment resources as a side effect of constructing the High Aswan Dam (HAD) and other water control structures along the Nile River. The shoaling inside the outlet leads to hindering the navigation process of fishing boats and negative impacts to estuarine and salt marsh habitat and decrease the efficiency of the cross section to transfer the flow during emergencies to the sea. Although protection works have been constructed to mitigate shoreline erosion and a frequent dredging has been carried out to overcome the siltation problem inside the outlet, the situation is still unstable as there is no enough attention to the severe erosion in front of the seawalls and that dredging causes instability in River Nile abatement. An integrated solution for both problems has not been achieved yet.

This study investigates different alternatives of hard and soft measures attempting to find an optimal solution for these problems (erosion and accretion) to enhance the stability of the promontory. The used integrated approach includes

A. Masria (✉)
Faculty of Engineering, Irrigation and Hydraulics Department, Mansoura University, 60 Elgomhoria st., Mansoura 35516, Egypt
e-mail: ali_masria@yahoo.com; ali_maaasria@mans.edu.eg

A. Negm
Department of Water and Water Structure Engineering, Faculty of Engineering, Zagazig University, Zagazig, Egypt

Department of Environmental Engineering, Egypt-Japan University of Science and Technology E-JUST, New Borg El-Arab, Alexandria, Egypt
e-mail: amnegm@zu.edu.eg; amnegm85@yahoo.com; negm@ejust.edu.eg

M. Iskander
Coastal Research Institute, Alexandria, Egypt
e-mail: coastal_alex@yahoo.com

A.M. Negm (ed.), *The Nile River*,
Hdb Env Chem (2017) 56: 275–302, DOI 10.1007/698_2016_104,

developing a calibrated/validated hydrodynamic and particle tracking model based on the 2D Coastal Modeling System software package (CMS).

Keywords Hard structures, Nourishment, Numerical modeling, Promontory

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1 Introduction

Estuaries are unique water systems; they are interfaces between fresh river water and saline coastal water [1]. In addition, they have a considerable impact on adjacent shorelines that they interrupt by influencing the sediment budget [2]. Although outlets play an important role in exchanging water and providing a navigational pathway for ships and small boats to travel between the open oceans and sheltered waters [3], they are increasingly influenced by human interventions such as maintenance dredging and land reclamation in the basin [4, 5].

Nile Delta coast is located in the middle part of the Mediterranean coast between Abu-Quir headland in the west and Port Said in the east with total length of about 240.0 km. The old Nile Delta comprised several branches that silted up. The flow is becoming restricted to two active branches, Rosetta and Damietta [6]. Each of these two branches developed a major promontory at its Mediterranean terminus [7]. Delta coastlines such as the Nile Delta are experiencing significant levels of erosion. The Nile Delta coast is highly dynamic and subjected to severe morphological changes, especially around the two branches of the River Nile: Rosetta and

Damietta. The main reasons for the erosion around the Nile promontories are generally cessation of sediments supply from the River Nile due to (1) construction of dams (Aswan low dam in 1902, Aswan high dam, in 1964) about 1,100 km from the river mouth; (2) construction of river flow control structures, in the form of regulators and barrages, on the upper and lower Nile River; and (3) natural reduction of Nile floods due to climate changes from and at the main source of the River [8, 9].

1.1 Hydrodynamic Classifications of the Outlets

Tidal outlets at many coastlines are found in a wide range of sizes and shapes. The variability in oceanographic, meteorological, and geological factors, such as wave energy, tidal range, and period, availability of sediment supply, fresh water discharges, and the interaction of these factors are responsible for this wide range in tidal outlet settings [10]. One approach has been to use energy-based criteria, in which outlets are classified based on the *hydrodynamic processes*, i.e., they are ranked according to the wave energy and tidal range of the environment in which they are located. In an early classification by Hayes [11], the coast is classified into three major categories based on tidal characteristics. They are micro-tidal (tidal range < 2 m), meso-tidal (2–4 m), and macro-tidal (>4 m).

Based on wide observation of coastlines around the world, three categories were identified based on the *morphological trends* of coasts and transformed it into classification scheme which is the most popular among geomorphologists [12]. This classification is concerned not only with the morphological behavior of a tidal outlet but also with the frequency of occurrence and number of inlets along a barrier coastline [13].

The first type is "wave-dominated coast or *micro-tidal*"; wave-dominated outlets tend to be small relative to tide-dominated outlets. It is dominated by washover features, and the tidal outlets occur infrequently along the coast with well-developed flood tidal deltas, but ebb-tidal deltas are small or nonexistent due to the dominance of wave energy [12, 13]. The second type is "mixed-energy or *meso-tidal*" environment; at mixed-energy tidal outlets, the shape and size of the delta are due to combination of tidal and wave processes. The size of flood tidal deltas basically depends on the magnitude of the tidal prism exchange between the back barrier basin and the ocean [13]. The last type is *macro-tidal*; the barriers do not develop well due to the dominance of strong tidal currents in cross-shore orientation. Wave-driven sediment transport plays a secondary role in modifying the shape and dimension of these inlets. Because most sand movement is in onshore-offshore direction, the ebb-tidal delta overlaps a relatively small length of outlet shore.

1.2 Parameters That Govern Estuary Stability

The governing variables of estuaries stability include tides, river discharge, atmospheric forcing, local geomorphology, wave, sediment supply, spatial distribution of backbarrier channels, slope of the nearshore, and engineering interventions. At tidal inlets, stability is controlled by the tides that scour the inlet throat and by the littoral drift of sand toward the inlet which creates the accumulation of the sediments inside the system from the seaward end. Hence, the complexity of modeling these processes at inlets where tidal currents, littoral drift, waves, and the presence of structures all plays a role [14].

Many different hypotheses have been brought forward to explain the inlet closure [15–18]. The *first mechanism* is due the interruption of longshore current and thus the longshore sediment transport by tidal inlet. Consequently, a shoal will be formed updrift of the inlet, where the growth rate of shoaling will depend on the intensity of longshore sediment transport. As the shoal grows more, a spit across the inlet emerged. If the inlet current is strong enough to remove the sediment that is being deposited in the channel mouth, then there will be no advance for the spit. However, if the inlet current is not strong enough to erode the settled sediment, the spit will continue to accrete and prograde until the inlet is completely blocked [18]. The *second mechanism* existed only in micro- or meso-tidal inlets due to the cross-shore transport. It is based on the interaction between the weak inlet current and onshore sediment transport due to swell wave conditions, and also the longshore current and longshore sediment transport rates are small to be considered. Under stormy conditions, the sand eroded from the beach, and surf zone is transported offshore resulting in the formation of a longshore bar at the breaker position. When the storms calm down and long-period swell waves start to dominate, sand stored in the offshore bar will be transported onshore and obstructed particularly opposite the inlet [19]. When the stream flow reduces in summer and the ebb current weakens, continuous onshore sand transport due to swell wave conditions will cause the closure of the inlet [18].

1.3 Previous Approaches for Mitigating Inlet Problems (Case Studies)

Various estuaries may be differently influenced by sea level rise, wave action and tides [2, 20], and anthropogenic influences, including direct impacts affecting river discharge and sediment load such as water diversion, deforestation, dams construction, and water diversion for irrigation which alter the morphology of deltaic systems [21]. The estuarine process response to both natural and human-induced forces requires a sufficient knowledge of the system's functioning, both for natural (physical and biological) and human interventions and corresponding interactions. Human interference in hydraulic systems is necessary to maintain and extend economic activities related to ports and associated navigation channels. In many situations, engineering structures are required to stabilize the shoreline, shoals, and inlets, to reduce sedimentation, to prevent or reduce erosion, or to increase the channel depth for navigation [22]. Shorelines may suffer from large-scale and small-scale sedimentation and erosion processes [23]. Erosion often occurs in places where sediment cannot be supplied by nature in sufficient quantities because it is trapped in another part of the system. The trapping can be due to natural causes or due to man-made changes in the system [23]. Dramatic examples of side effects are presented by Douglass [24], who stated that about one billion m^3 of sand are removed from the beaches of America by engineering works during the last century. Nourishment and bypassing of sand are often required to mitigate the unavoidable side effects of engineering works. It is important to emphasize that engineering works should be designed and constructed or built in harmony rather than in conflict with nature. This "building with nature" approach requires a profound understanding of the sediment transport processes in morphological system coastal erosion [23].

For example, Scheide estuary, which is situated in the southwest of the Netherlands and Belgium, was influenced by both natural processes and human interferences that affected the morphological evolution over the past two centuries [25]. These interferences represented in the reclamation of intertidal lands which resulted in a permanent loss of intertidal areas and sand extraction, dredging, and dumping to deepen and maintain the navigation route to the port of Antwerp. On the other hand, soft measures become popular nowadays as it build with the nature like sand nourishment at the beach face or nearshore zones. For example, to mitigate the erosion of the southern Gold Coast beaches (SE Queensland, Australia), significant nourishment works have been undertaken over the past 30 years. This project involved nourishment of the nearshore and upper beach using sand sourced from inactive offshore deposits.

In Huanghua port in China located at Bohai Sea, sediment deposition accumulated in large quantities and blocked the navigation channel at the shoreline [26]; to overcome this problem, two jetties were constructed on soft clays at Huanghua port to protect the channel from deposition due to longshore transport.

Another example, Guadiana estuary, in South Western Iberian Peninsula suffers from the reduction of water discharges due to the construction of series of large barrages and dams. This estuary mouth is dominated by a large sandbank. The highly dynamic character of this bank frequently led to extensive problems for the shipping traffic. In an attempt to control the migration of the bank and avoid further infilling of the main estuary channel, two large jetties were built between 1972 and 1974, bounding the side boundaries of the main river channel.

In USA, the US Army performed a structural solution involving new jetties at the mouth of the Colorado River (MCR), Texas, as the site has experienced excessive sediment shoaling. This new jetty was expected to give a permanent structural solution that would reduce dredging frequency while maintaining a reliable channel [27].

1.4 Critical Evaluation of the Previous Studies

It is clear from literature review that the construction of artificial structures or the dredging of sediment is the predominant trend to overcome siltation inside the inlet and the nourishment to mitigate erosion problem. Generally, two approaches (hard structures and nourishment) are used to solve coastal problems represented in erosion and accretion. But, up till now, the combination between the soft and hard measured has not been tried numerically on wide range to reach such an integrated solution. For this reason, this study comes online to cover this gap in order to enhance the long-term stability conditions at Rosetta outlet, Mediterranean coast of Egypt, using an integrated approach.

2 Case Study (Rosetta Promontory)

2.1 Study Area and Location

Rosetta promontory is one of the most vulnerable areas and lies on the northwestern Nile Delta coast as shown in Fig. 1. Generally, the promontory is a coastal headland with flat terrain covered by sand mounds and small sand dunes. The beach is composed of fine to very fine quartz sand and rich in heavy minerals [28]. There are many low-lying areas forming salt-crusted sabkhas. The headland is inundated periodically by seawater during winter storms. Agricultural lands encompass the River Nile course. Urban areas include the city of Rosetta along with many other small villages.

2.2 Problem Statement

Delta coastlines such as the Nile Delta are experiencing significant levels of erosion. The Nile Delta coast is highly dynamic and subjected to severe morphological changes, especially around the two branches of the River Nile: Rosetta and Damietta. Rosetta promontory is an example of many outlets that suffers from

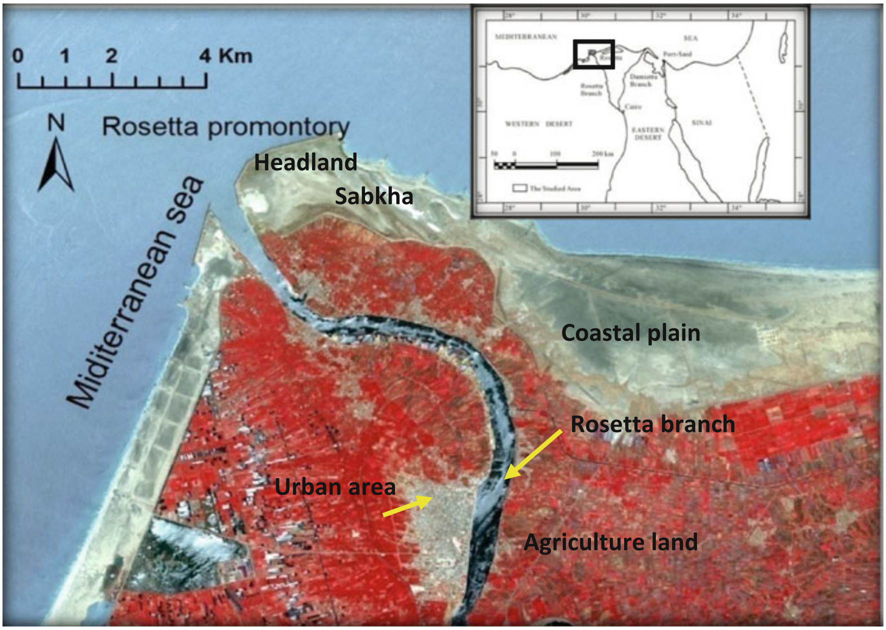

Fig. 1 Rosetta promontory at the terminal of Rosetta branch, SPOT image, 2012

many coastal problems such as erosion along the coastline. It is due to lack of water and sediment resources of the Nile River as a side effect of constructing the water control structures mainly High Aswan Dam (HAD) along the River Nile [29]. Moreover, Rosetta outlet considered as a sink for the eroded sediments transported offshore from Abu Quir Bay and Rosetta [30]. These sediments accumulate at the outlet and result in greater problems for navigation process and the living of habitat in this area and also threaten the nearby areas with inundation in flood conditions as it reduce the capacity of the waterway cross section. Moreover, frequent dredging was carried out to overcome the siltation problem inside the outlet, but the situation is still unstable [11, 16].

Although protection works (two revetments of 5 km long and 14 groins east and west of the promontory) were constructed to mitigate the erosion problem at Rosetta outlet [31], the shoreline along Rosetta promontory is still unstable, and the protection works have not been efficient enough to stop erosion [32].

2.3 *Previous Studies and Filling the Gap*

There is a considerable interest over the last decades in the marked coastal changes observed along Rosetta promontory, leading to studies of coastal geomorphology, analysis of beach profiles up to the 6 m depth, aerial photography analysis, satellite image analysis, shoreline changes, dynamic factors, and sediment transport. Previous researches focused on mitigating erosion problem at the eastern side of the revetment by Elsayed and Mahmoud [33] and western side by Ahmed [34] with hard structures. On the other hand, the siltation problem inside the Rosetta estuary were investigated through testing jetties on the inlet boundary, and it was recommended a frequent dredging to overcome the siltation problem inside the estuary.

In conclusion, previous works tried to overcome each problem alone at the eastern and western side of the revetments with hard structures, but there was no enough attention to the severe erosion problem in front of the seawalls. In addition, the integrated solution for both problems was not achieved yet.

3 Methodology

3.1 Data Sets

The field data (bathymetry, wave, tide, and Nile River discharges) were obtained from the Coastal Research Institute, Hydraulics Research Institute, and Coastal Protection Authority. In addition, geometric data include land boundary, land elevations, groins elevations, and Rosetta branch position which were used in determining the closed, open boundaries of the model and creating the grids. The bathymetric survey (about 50 profiles which are perpendicular to the coastline) utilized in this study was conducted in October 2005. Figure 2 shows the bathymetric map of the promontory. The bathymetric survey of May 2006 was used to calibrate the numerical model. The wave data are the averaged wave climate of 5 years between 1986 and 1990. The wave directions are from WNW, NNW, N, and W with a small portion of waves arriving from the NNE and NE especially in March and April [35].

The Nile Delta coast is a typical micro-tidal semi-diurnal tidal regime with a tidal range of 30 cm [36]. The available tide data represented in water levels at Rosetta promontory covered the period from October 2005 to October 2006. The sediment grain sizes (d_{50}) at the nearshore zone of the area of interest are between 0.16 mm and 0.24 mm based on previous study by [34]. In order to transform the wave from offshore station at depth 18 m to the model boundary at 11 m depth, the maximum entropy code (by CMS developers) was applied for the directional spectrum to be ready as input in the model.

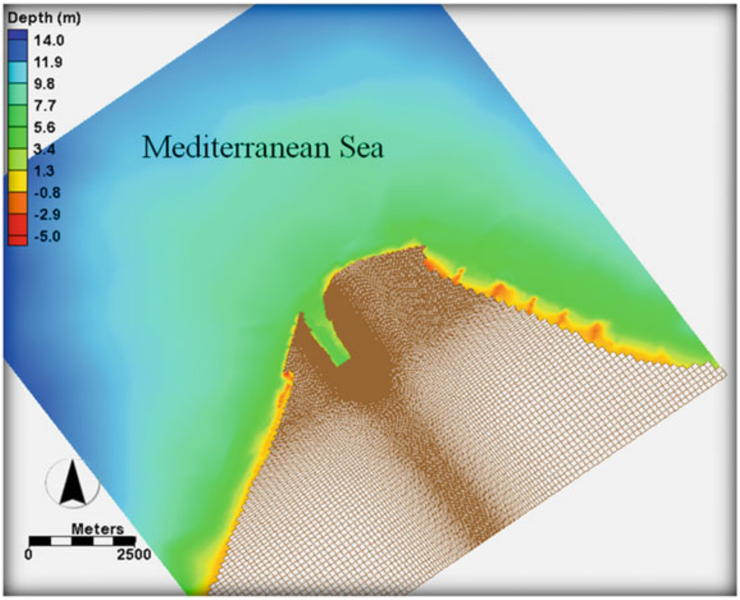

Fig. 2 Model domain of Rosetta estuary, depths (positive) are relative to mean sea level

3.2 Hydrodynamic Model Setup

An accurate bathymetric grid is essential because wave propagation is strongly influenced by nearshore bathymetry. In addition, high spatial resolution is necessary to adequately resolve the inlet. The nearshore, offshore, the inlet, Rosetta branch, and adjacent beaches were surveyed between 2005 and 2006 by Coastal Research Institute. The CMS grid was constructed based on the abovementioned bathymetric data. A variable-sized rectangular-cell grid system, with a spatial resolution ranging from 20×20 m in the vicinity of the inlet, and the nearshore zone, navigation channel to 70×120 m near the sea boundary, was generated with a number of ocean cells = 24,613. Having the fine grid spacing at and around the estuary enabled capturing the sediment transport and morphologic change processes where they mainly occurred. The larger the offshore grid spacing, the speeder the computational process is. A CMS-Wave was also generated that had the same dimensions as flow. To simulate the flow field, CMS-Flow was driven by the measured tide along the open boundaries from October 2005 to October 2006. After examining the 5-year (1986–1990) records, wave during 1986 was judged to be representative and used in the modeling effort. The half-plane model of CMS-Wave was selected for this study. Figure 3 shows both CMS-FLOW and CMS-WAVE grids.

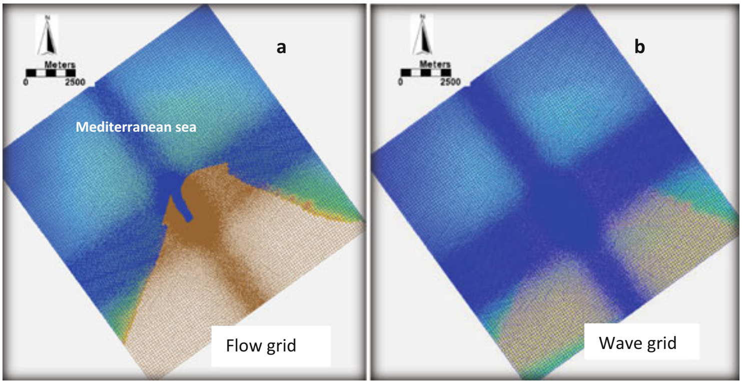

Fig. 3 Model grids with boundary condition for Rosetta Promontory, resolution increases at the vicinity of the mouth and the surf zone, (**a**) CMS-Flow grid, and (**b**) CMS-Wave grid

Fig. 4 Location of the selected profiles along eastern and western sides of Rosetta outlet used in calibration and sensitivity analysis

3.3 Model Calibration and Validation

To calibrate the model, bathymetry evolution maps (October 2005 and May 2006) were used. Input data for the wave and flow mode were prescribed, and the model was executed to predict the bottom evolution after 6 months starting from October 2005 to May 2006.

Several profiles were considered at western and eastern sides of the outlet as shown in Fig. 4 to perform sensitivity analysis and model calibration. The important parameters used calibration hydrodynamic time step (300, 450, and 600 s),

Table 1 Correlation coff. and Brier skill score of profiles due to bed depth and bed change

Section name	R^2 (bed depth)	R^2 (bed change)	BSS (bed change)	RMSE (bed depth)
RHP30	0.98	0.60	0.612	0.061
RHP29	0.99	0.50	0.483	0.052
RHP24.8	0.97	0.70	0.683	0.083
WBP4.6	0.95	0.36	0.320	0.091
WBP8.8	0.97	0.34	0.316	0.078
WBP9.6	0.94	0.38	0.351	0.132

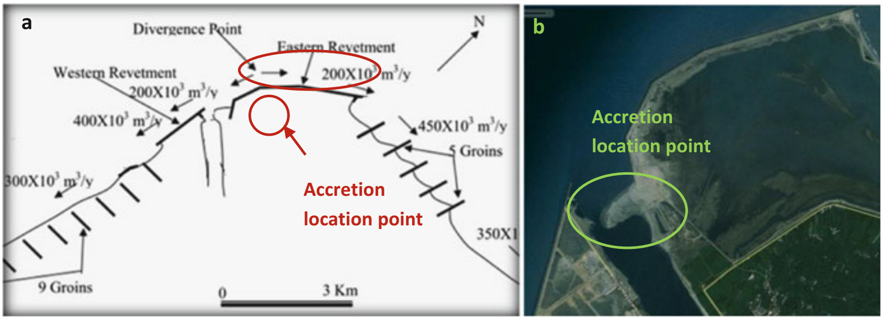

Fig. 5 (**a**) Location of the divergence (nodal point) [37], (**b**) location of the sedimentation inside the outlet, Google Earth, 2007

Manning coefficient (0.009, 0.125, 0.025, 0.04, and 0.05), different transport formulas (Van Rijn, Land-Cirp, and Watanabe), scaling factor (0.5, 0.7, 0.9, 1.0, 1.3, and 2.0) for bed load and suspended load, total adaptation length (1, 5, 10, 20, 50, and 100), and also the effect of smoothing the bathymetric contour.

The squared correlation coefficient according to bed change, bed depth, Brier skill score (BSS), and Normalized root mean square error (NRMSE) was calculated for all profiles. The results show that our model is qualified to predict the coastal morphodynamic processes as shown in Table 1 with 0.025 of Manning coefficient, 450 s time step, scaling factor of 2.0, and adaptation length of 10 m. Moreover, the model was validated through comparing model results with the previous published studies and Google Earth image as shown in Fig. 5 [37]. From these figure, it is clear that the model results as shown in Fig. 6 succeed to present the nature in a good way represented in the exact location of the nodal point (divergence point, where the current flow diverges to the east and west) and the sedimentation inside the inlet.

The output of CMS like wave transformation, flow circulation, water levels, and sediment transport will be used as inputs for PTM model. In addition, native sediment data, source file, and boundary cell strings were created, and then CMS-PTM parameters could be specified in order to simulate the spatial distribution of nourishment material in the open water after releasing from the source in

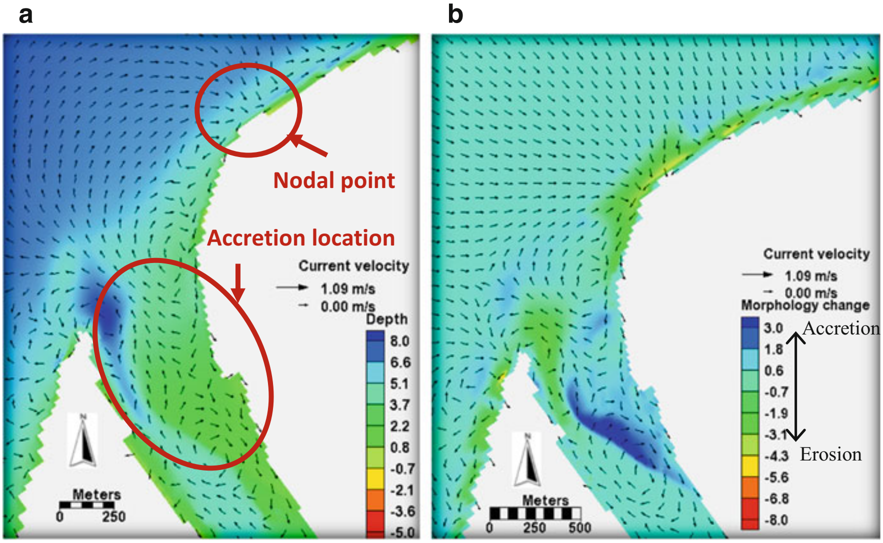

Fig. 6 Location of the divergence (nodal point) and sedimentation inside the outlet for the simulation results based on (**a**) water depth and (**b**) morphology change

terms of identifying the suitable locations for the placement sites and the proper grain size of the used sediments and describing the qualitative behavior of the particle state (suspended and deposited) during and after nourishment process.

The validation of PTM was conducted through comparing its results with a fluorescent tracer study performed by Abo Zed and Shereet [38] along Rosetta coast to predict the direction of sediment movement and to estimate the sediment dispersion at the western side of the promontory and near Rosetta outlet as shown in Figs. 7 and 8. The results of PTM simulation gives a good correlation with the experimental one as it gives almost the same grain size distribution as shown in Fig. 9.

4 Results and Discussion

The proposed scenarios in this section are seeking for an integrated solution to maintain the stability at the promontory. This approach is conducted by supplying sediments (sand nourishment) in front of revetments and increasing flow discharges (diverted discharges from Burullus Lake). The sediments are supplied through the following nourishment techniques: beach nourishment and nearshore nourishment. In addition, the combination between the nourishment methods and the hard structure is performed. All alternatives are tested by Coastal Modeling System

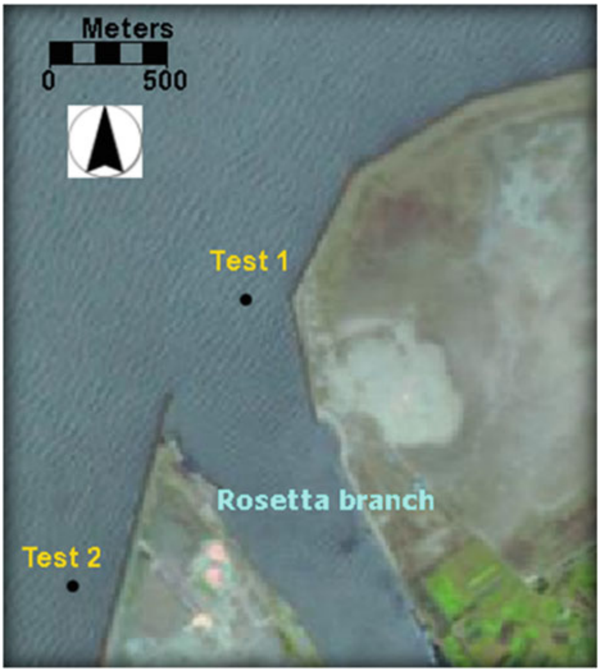

Fig. 7 Location map of fluorescent sand tracer experiments [38] and PTM sediment release points

software. However, Particle Tracking Model (PTM) is conducted first to simulate the spatial distribution of nourishment material in the open water after releasing from the source in terms of identifying the suitable locations for the placement sites and the proper grain size of the used sediments and describing the qualitative behavior of the particle state (suspended and deposited) during and after nourishment process.

The nourishment scenarios will be conducted through the following steps:

(a) Running Coastal Modeling System (CMS) before adding nourishment, as CMS outputs like wave transformation, flow circulation, water levels, and sediment transport will be used as inputs for PTM
(b) Running Particle Tracking Modeling software to identify the suitable locations for the placement sites and the proper grain size of the used sediments and the renourishment factor
(c) Conducting different nourishment scenarios using CMS after getting results from PTM (best placement site, proper grain size).

Modeled bathymetric evolution, morphological changes, total sediment transport, sediment concentration, wave height distribution, and current velocity contour are extracted for each scenario based on Coastal Modeling System package. Six cross sections inside Rosetta outlet were utilized to investigate the effect of the

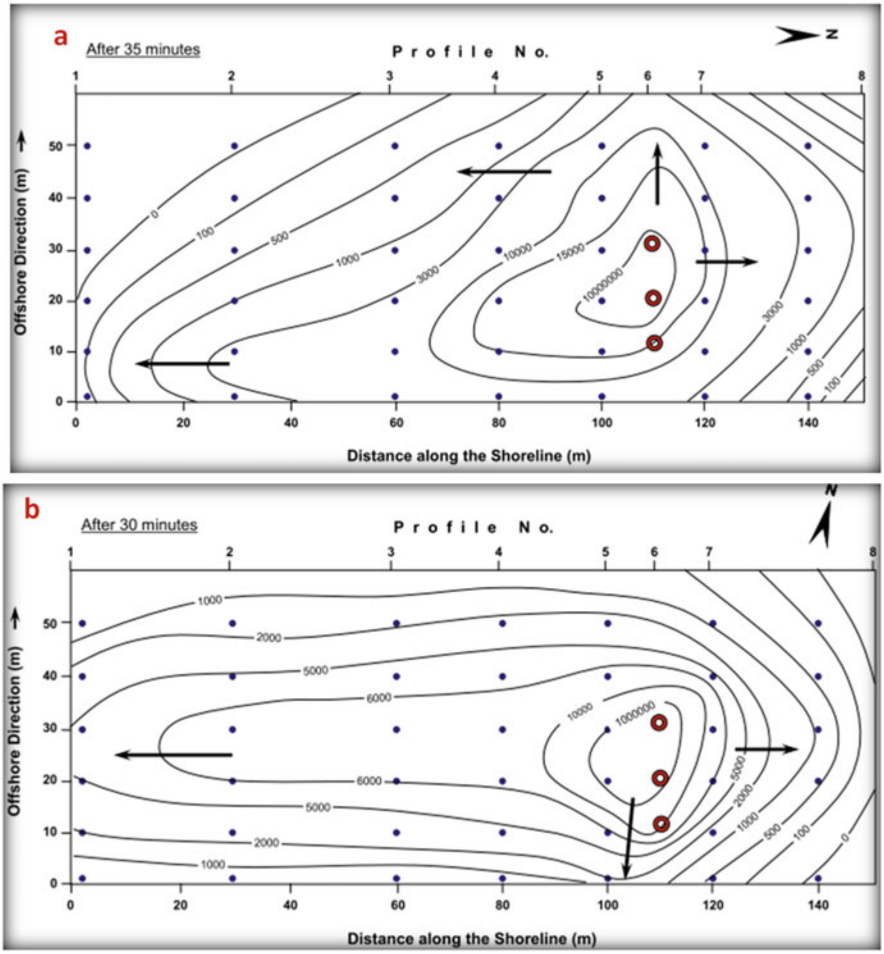

Fig. 8 (**a**) Dispersion of fluorescent sand tracer at 3 km west of Rosetta outlet, (**b**) dispersion of fluorescent sand tracer at Rosetta outlet [38]

morphology of outlet cross section for the different scenarios, in addition to nine beach profiles to investigate the effect of the different alternatives on the coastal area as shown in Fig. 10.

The better solution will be selected based on the following criteria: (1) decreasing the sedimentation inside the outlet, (2) keeping the inlet cross section suitable for navigation and flood (releasing huge water discharges during Nile flood), (3) decreasing erosion rate in front of the seawalls, and (4) lowering construction cost and being environmentally friendly.

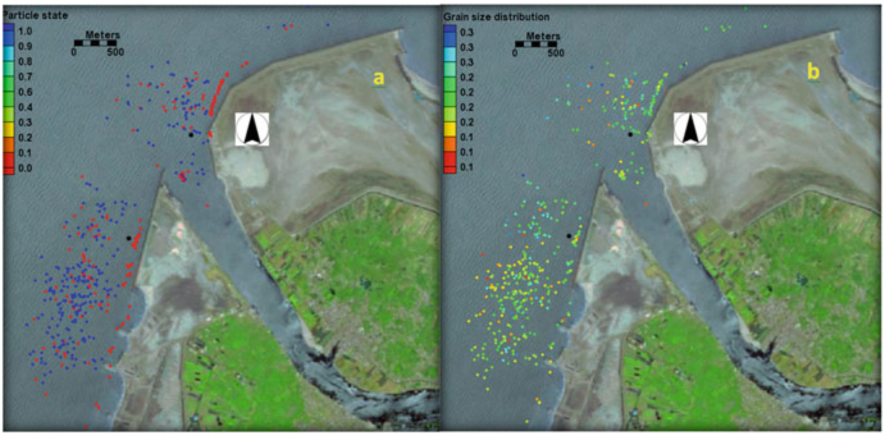

Fig. 9 Results of PTM model at the mouth and western location: (**a**) particle positions showing sediment in suspension (*blue*) and deposited (*red*) and (**b**) grain size distribution

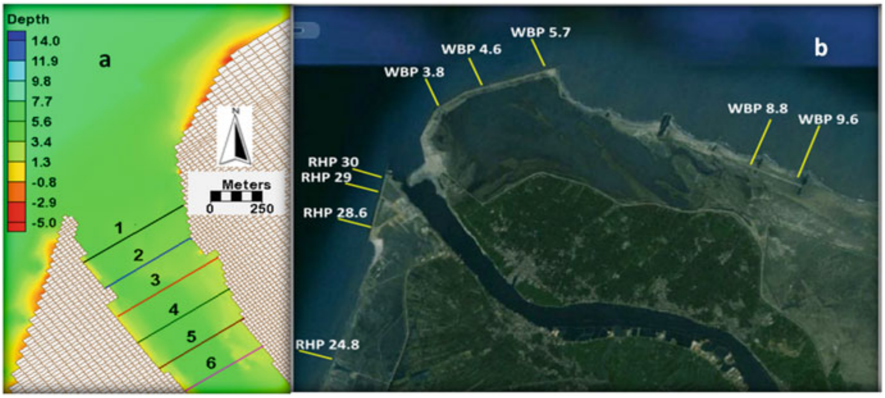

Fig. 10 (**a**) Cross sections through the outlet used in the comparative study, (**b**) location of the selected profiles along eastern and western sides of Rosetta outlet used in the comparison

Firstly, the nearshore nourishment scenarios were selected based on the Particle Tracking Model (PTM) results. For more information about PTM results, you can refer to [39].

4.1 Nearshore Nourishment Group

The proposed placement sites of the nourishment material (black boxes) are selected according to the hotspots of erosion as well as the nodal point in the eastern side of the promontory where longshore sediment transport is diverted to east and west as shown in Fig. 11. The checked sediment volumes are 100,000, 200,000, and

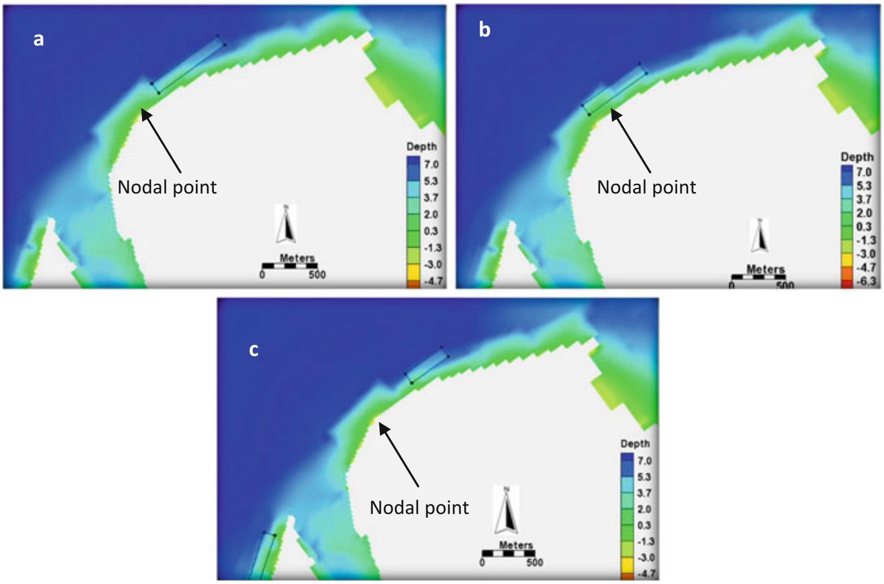

Fig. 11 The three proposed scenarios for nearshore nourishment sites related to nodal point

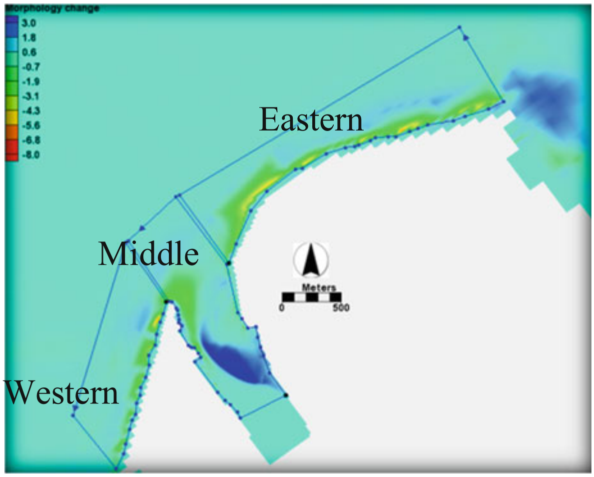

Fig. 12 Three subareas used to estimate the annual sediment volume

300,000 m^3. Nourishment material was placed at an average depth of 5 m. For each sediment volumes, three scenarios were tested: (1) placement site is directly at the right side of the nodal point (eastern side of the promontory), (2) the placement site is centered above the nodal point at eastern side of the promontory, and (3) the sediment volume is distributed equally at the site east and west of the promontory.

To accurately check the effect of the different scenario with different volumes, the hotspot area was divided into three subareas: the eastern, middle, and western as shown in Fig. 12.

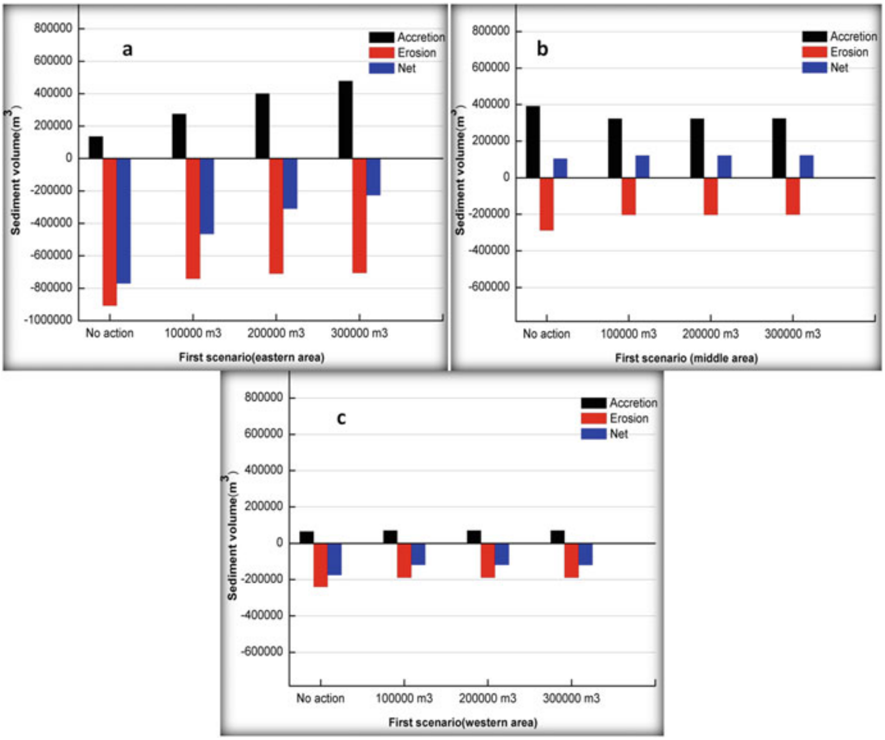

Fig. 13 Annual sediment volume of the first scenario for different nourishment volumes (100,000, 200,000, and 300,000 m^3): (**a**) eastern area, (**b**) middle area, and (**c**) western area

Figures 13, 14, and 15 represent a comparison of sediment volume change between different scenarios. Although the second set of scenarios with sand volume (300,000 m^3) is slightly better than the other in comparison with no action scenario, it is clear that there is no significant effect of the nearshore nourishment technique in decreasing the severe erosion in front of the seawalls. On the other hand, it did not solve siltation problem inside the inlet.

4.2 Effect of Soft Measures (Nourishment) and Hard Measures (Structures) Combinations

From the abovementioned alternatives, it was found that nearshore nourishment is not sufficient to mitigate the promontory problems. So in this section, we tried to combine it with the hard structures in order to trap the longshore sediment that present the key for erosion problem. At the same time, it will act as a barrier that stops sedimentation to be directed inside the inlet whether from the eastern nodal point or the western side. So, in this section, firstly, the best scenario (second one

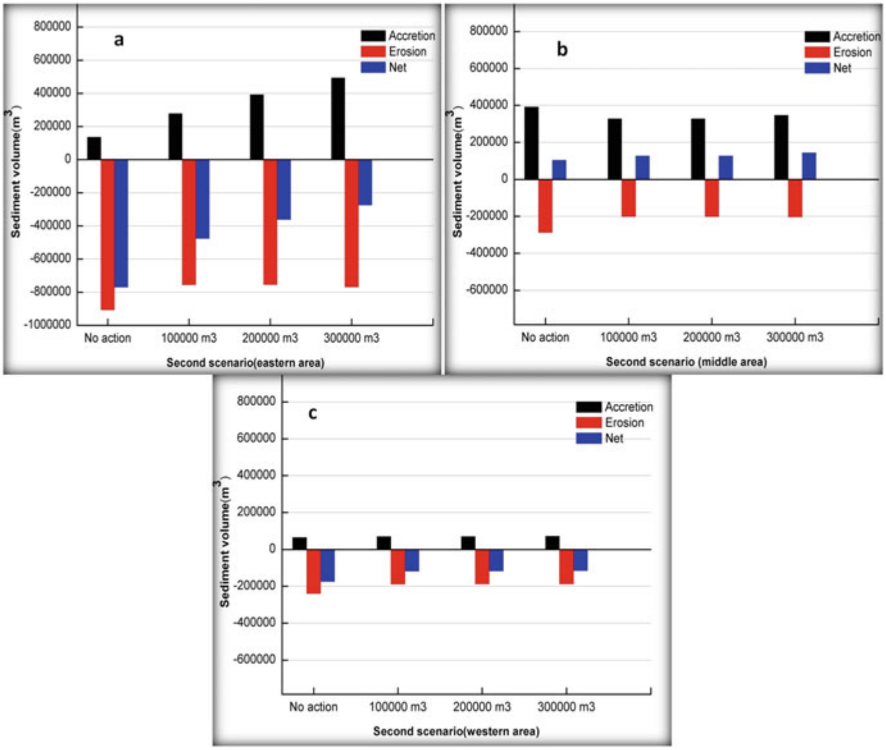

Fig. 14 Annual sediment volume of the second scenario for different nourishment volumes (100,000, 200,000, and 300,000 m^3): (**a**) eastern area, (**b**) middle area, and (**c**) western area

with 300,000 m^3) that resulted from the nearshore alternatives will be checked with hard structures.

4.2.1 Nearshore Nourishment (Second Scenario with Sand Volume of 300,000 m^3)

In this section, two scenarios are tested. The first scenario includes the best from the nearshore nourishment (placement site is at eastern side centered on the nodal point for sand volume of 300,000 m^3) with an inclined groins at the western revetment (to prevent the erosion to occur at the western tip of the revetment) and eastern jetty of 360 m length (to prevent the accumulation of the sediments through nodal point inside the inlet). The second scenario is the same as the first one; the only difference is that the eastern jetty is inclined. Figure 16 shows the two proposed scenarios in this section.

Figures 17 and 18 show the morphology change and annual sediment volumes after 1 year, for the two scenarios. It is illustrated from this figure that the both scenarios enhance the inlet stability compared to the no action case in terms of

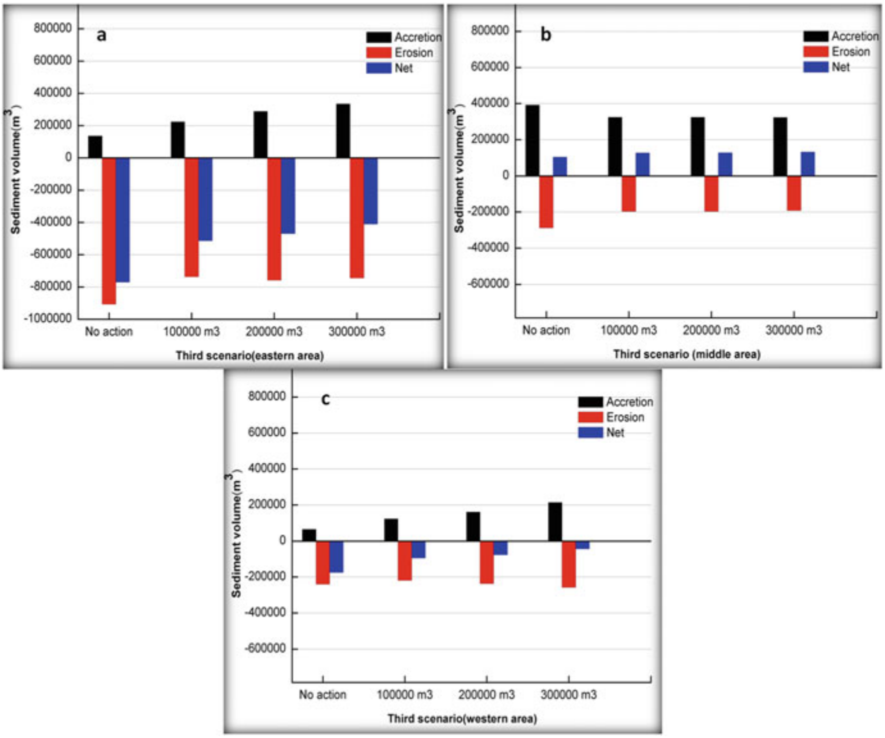

Fig. 15 Annual sediment volume of the third scenario for different nourishment volumes (100,000, 200,000, and 300,000 m^3): (**a**) eastern area, (**b**) middle area, and (**c**) western area

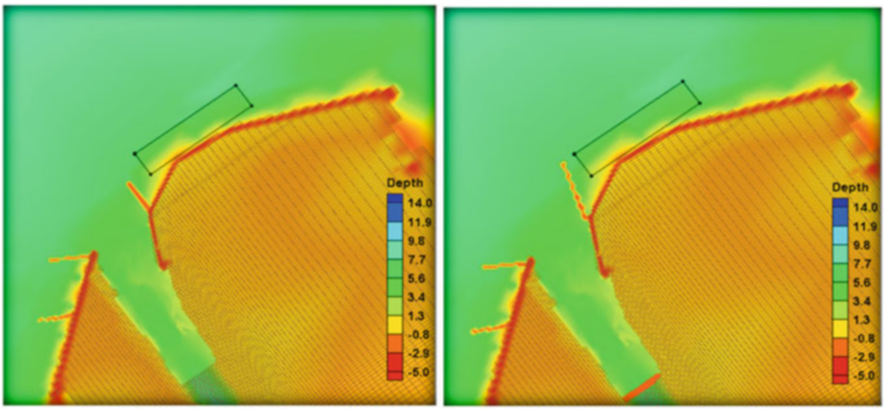

Fig. 16 The two tested scenario (combination between the best scenarios in nearshore nourishment group with hard structures)

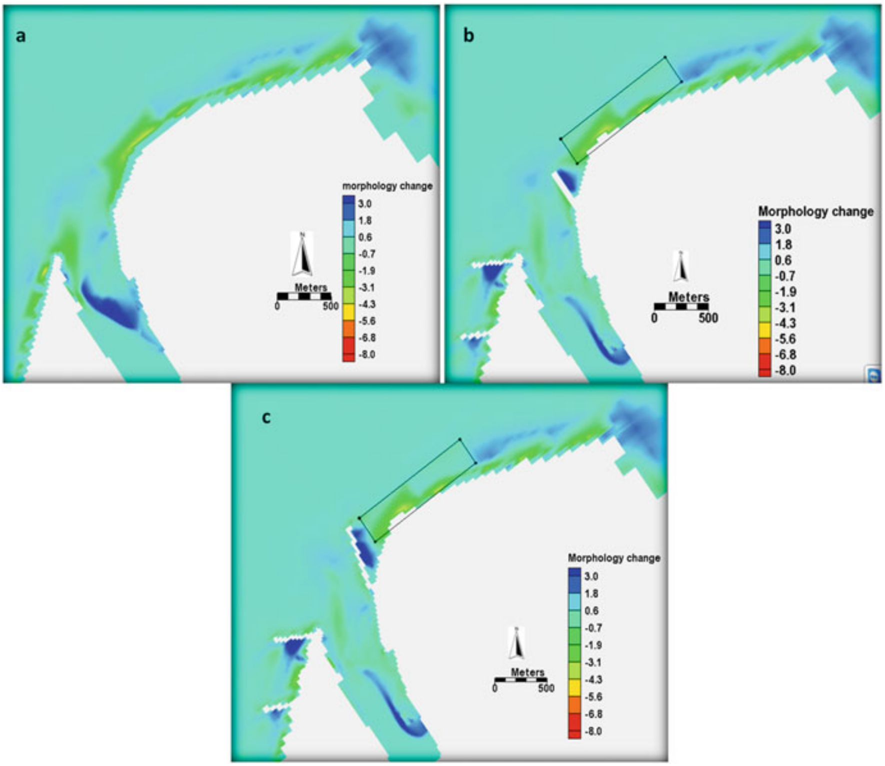

Fig. 17 Model results of the morphological changes of different nourishment scenarios (**a**) no action, (**b**) first scenario, and (**c**) second scenario

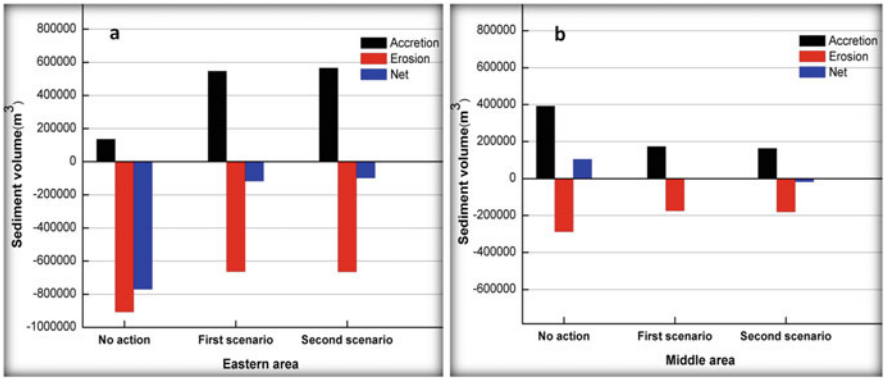

Fig. 18 Annual sediment volume of the two scenarios at (**a**) eastern area and (**b**) middle area

reducing the sediment accumulation inside the inlet. In addition, it decreases the erosion rate at the hotspot areas in front of the eastern and western revetments (especially the western one).

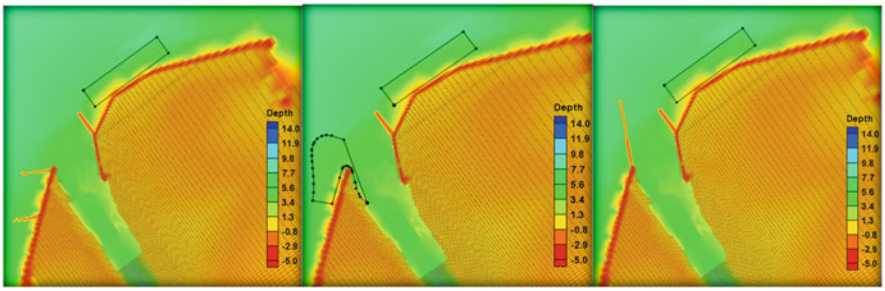

Fig. 19 The different scenarios combined between the hard and soft measures

Construction Cost

Generally, it is concluded that the both scenarios improve the stability of the promontory. So, the priority is according to the cost. The cost of the breakwater ranges between 6,000 and 8,000$ per meter and depends on the depth. For the sand nourishment, the cost ranged from 8 to 10$/m^3 depending on the location. For Rosetta, the hard structure can be roughly calculated as 7,000$ per meter and the nourishment as 9$/m^3, *Coastal Research Institute*.

- Cost for first scenario = (400 + 400 + 360)* 7,000 + (300,000*9) = 8,120,000$
- Cost for second scenario = (400 + 400 + 580)* 7,000 + (300,000*9) = 9,660,000$

So, according to construction cost, the best scenario from this group is the first one.

In this section, a comparison between the best options in the previous section in addition to two other scenarios is shown in Fig. 19. The second one includes an eastern jetty of 360 m length beside the nearshore nourishment (centered on the nodal point for sand volume of 300,000 m^3) and beach nourishment at the western part with sand volume of 300,000 m^3. The third one includes an inclined western jetty of 800 m length, an eastern jetty of 360 m length, and the nearshore nourishment (centered on the nodal point with sand volume of 300,000 m^3). It is clear from the morphological results as shown in Fig. 20 that the third scenario succeeded to decrease the sedimentation inside the inlet to its minimal rate.

It is concluded that the third scenario is the best solution as it reduces the accretion inside the outlet to its minimum levels besides reducing the erosion rate in front of the eastern and western revetment. But in order to maintain entire stability, we have to protect the western area from erosion. Accordingly, different volumes of beach nourishment (100,000, 200,000, and 300,000 m^3) will be tested with the "best" scenario. The results of seabed profiles at the western side of the promontory are extracted as shown in Fig. 21. It is clear that the volume 200,000 m^3 at the west is enough to stabilize the western area.

Moreover to estimate the periodic time to nourish the western and eastern part, 5-year simulation was performed. The results of the bed evolution outside and inside the outlet as shown in Fig. 22 show that it is better to nourish annually in front of the eastern and western areas with volumes 300,000 and 200,000 m^3,

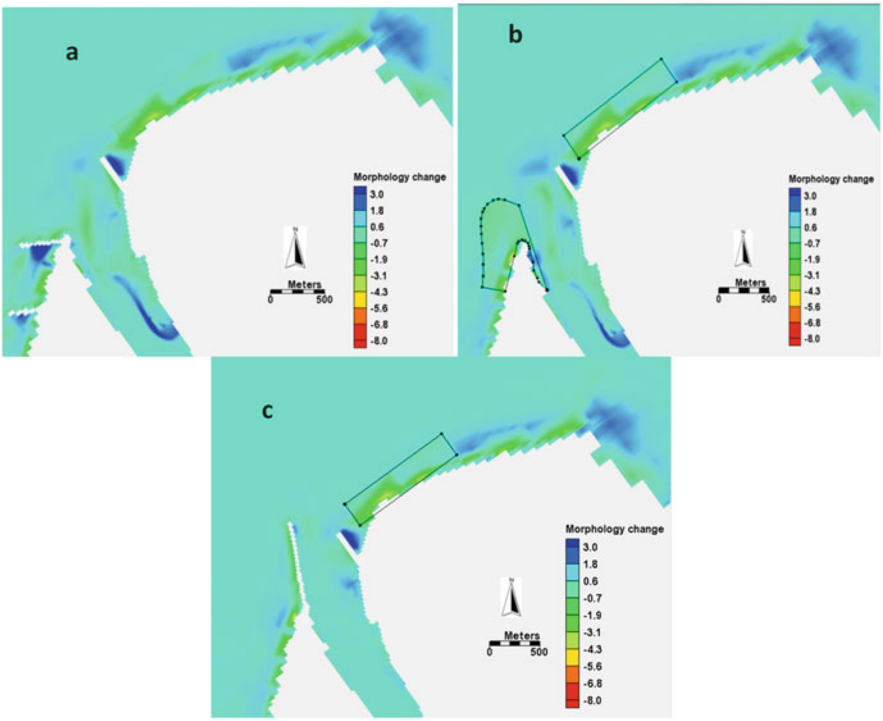

Fig. 20 Model results of the morphological changes of different three nourishment scenarios

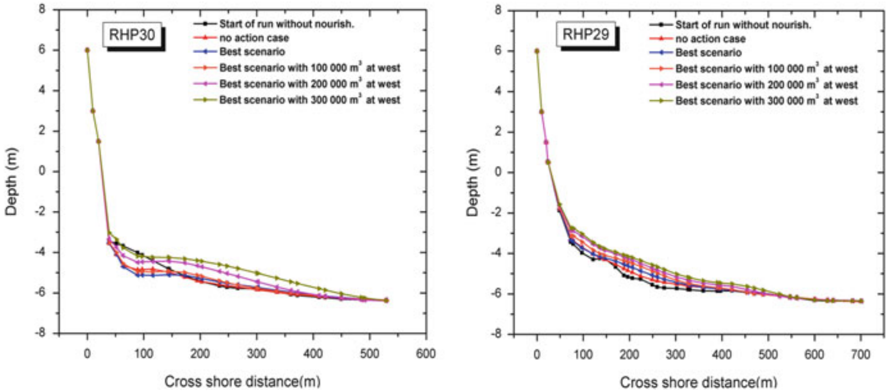

Fig. 21 Seabed profile results of the optimum scenario with different beach nourishment scenarios

respectively. In addition, the accumulated sediments behind the eastern jetty were calculated as 36,000 m^3. This amount should be dredged also every year to prevent bypassing sediments inside the outlet and bypassed to the nourishment sites.

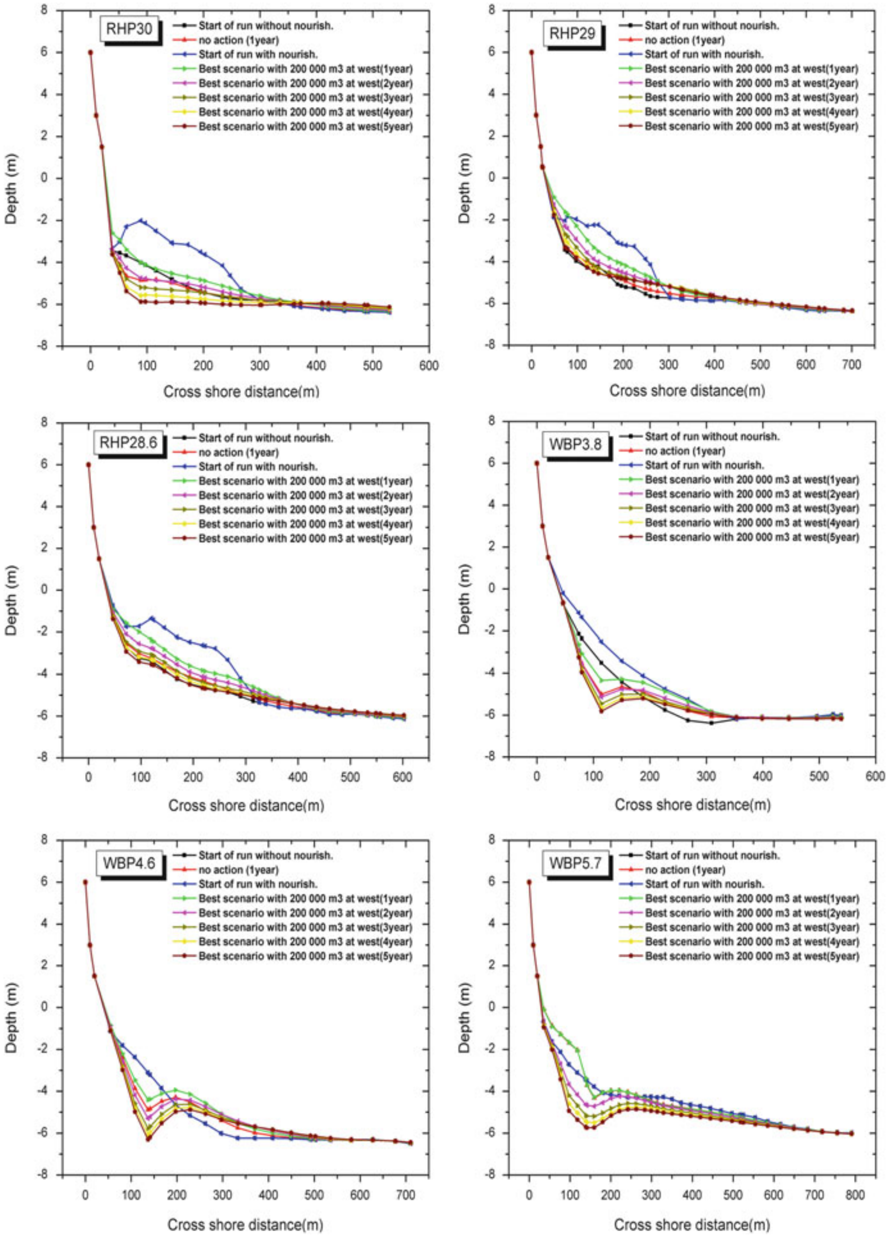

Fig. 22 Seabed profile results of the optimum scenario with nourishment volume 200,000 m^3 at the west

Generally, from the second approach, it is concluded that this optimum solution maintains the navigation process in addition to mitigating the erosion problem in front of the revetments.

4.3 Environmental Impact of Optimum Scenario

4.3.1 Morphodynamic Aspect

Figures 23, 24, and 25 show a comparison between the optimum solutions of the recent study with the no action case. It is clear that the optimum solution has improved the stability of the outlet represented in (a) decreasing the siltation inside the outlet which satisfies the navigation conditions and overcomes the erosion problem in front of the seawalls that threatens its stability as shown in Fig. 23.

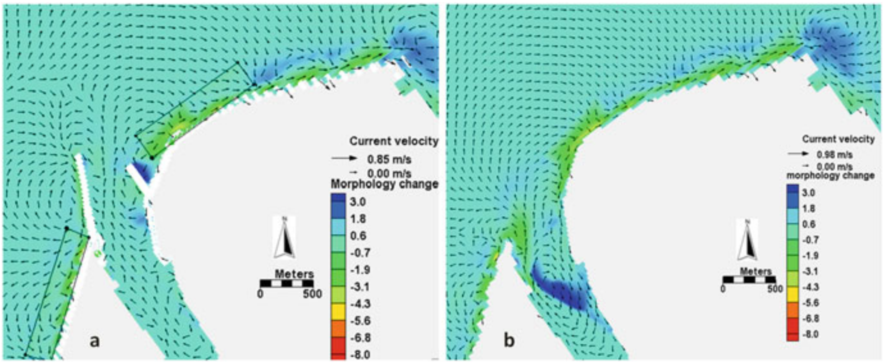

Fig. 23 Model results of the morphological changes of the (**a**) optimum and (**b**) no action scenarios

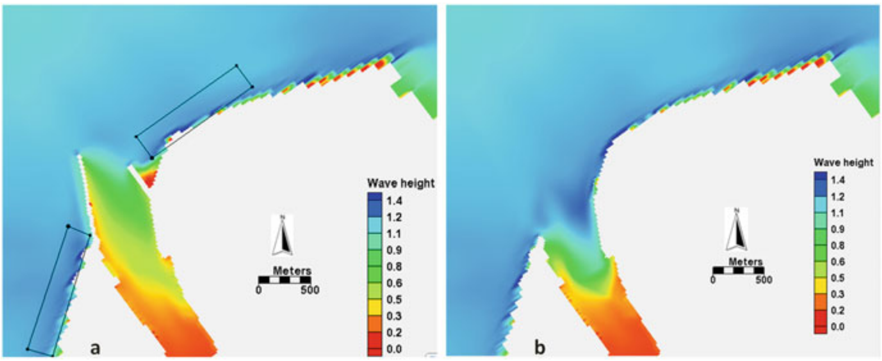

Fig. 24 Model results of the wave height distribution of the (**a**) optimum and (**b**) no action scenarios

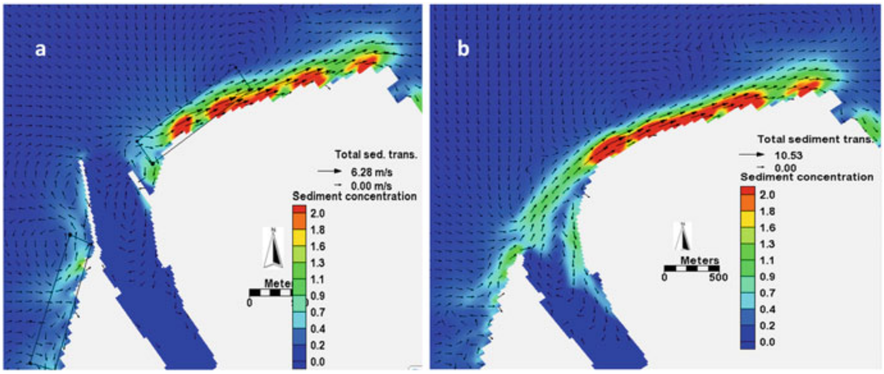

Fig. 25 Model results of the total sediment transport of the (**a**) optimum and (**b**) no action scenarios

On the other hand, it has decreased the wave height at the outlet compared to the no action case as shown in Fig. 23, which in turn leads to decreasing the wave energy at the outlet. Moreover, the total sediment transport at the outlet especially in front of the eastern seawall has been decreased as shown in Fig. 24. This decrease is due to the hindering of the littoral drift by the boundary jetties.

4.3.2 Environmental Aspect

The deterioration of Nile water quality is most pronounced in the Rosetta branch due to the disposal of municipal and industrial effluents, in combination with agricultural drainage and decreasing flow as water arrives at the Nile estuary [40]. In addition to nutrient-enriched waters, other pollutants such as trace metals and hydrocarbons of industrial origin are reaching the Nile estuarine environment. All of these pollutants have severely affected Rosetta outlet. There are numerous reports of high concentrations of contaminants such as aluminum, iron, copper, zinc, cadmium, and lead, dissolved and in particulate forms in waters contributing to the estuarine environment of Rosetta area. The particulate form is mostly associated with suspended matter (both organic and inorganic), which afterward is deposited as sediments [41].

The release of oil wastes into the Nile estuary is inevitable, and oil products are harmful pollutants adversely affecting the biota of the Nile estuary ecosystem. The variable levels of pollutant concentrations in the Nile estuary environment are related to the river discharging capacity, the distribution of land-sourced effluents along the Nile Delta region, and temporal variations in these factors. The eastward flowing Mediterranean currents along the Egyptian coast carry pollutants from the western effluents (Rosetta branch and coastal lakes) to the eastern side of the Delta.

In conclusion, the obtained scenario in the present will not affect the water quality nor the fish catch as the deterioration in both categories parallels the decrease in the discharged freshwater and fertile sediments after the construction of HAD.

5 Conclusion

Rosetta outlet experienced continuous erosion in front of the existing seawalls and accretion inside Rosetta outlet. To enhance the stability of the promontory, soft protection measures represented in sand nourishment are proposed. Nearshore nourishment is applied using a calibrated Coastal Modeling System software. The sediment sizes are selected according to the availability of the material and the distance from the site.

For the nourishment techniques, three scenarios were selected. For each scenario, three different volumes are selected (100,000, 200,000, and 300,000 m^3). It is observed that there is no significant effect on the stability of the promontory. This is due to hydrodynamic effect of the promontory with the revetment which transfers the sediment outside the desired area. So, the hard structures were tested in combination with the relatively better one from nourishment.

Through testing different combinations of hard and soft measures, it was concluded that optimum solution is to use a combination between soft measures (nourishment) and hard measures (jetties). This solution includes an eastern jetty of 360 m length and western jetty of 800 m, in addition to sand nourishment of (300,000, 200,000 m^3) in front of the eastern and western revetment, respectively. Within the tested scenarios, the optimum one has the following merits:

- The periodic sand nourishment will be every 2 years for the western part and 1 year for the eastern one.
- Moreover, a dredging work will be required behind the eastern jetty with 36,000 m^3 annually.
- The construction cost of this solution is estimated to be 9,920,000$.
- The annual maintenance cost will be 2,700,000$ every year for the eastern part of the promontory, while the western part will be maintained every 2 years with 1,800,000$. This cost includes sand nourishment only.

References

1. Horrevoets AC, Savenije HHG, Schuurman JN, Graas S (2004) The influence of river discharge on tidal damping in alluvial estuaries. J Hydrol 294:213–228
2. Stive MJF, Wang ZB (2003) Morphodynamic modeling of tidal basins and coastal inlets. Elsevier Oceanogr Ser 67:367–392
3. Lam NT, Stive MJF, Verhagen HJ, Wang ZB (2007) Morphodynamics of Hue tidal inlets, Vietnam. In: Proceedings of the Asian Pacific Coasts, pp 692–705

4. Bell R, Green M, Hume T, Gorman R (2000) What regulates sedimentation in estuaries. Water Atmos 8(4):13–16
5. Kraus NC, Kim YC (2009) Engineering of tidal inlets and morphologic consequences. In: Handbook of coastal engineering, vol 31. Chapter
6. Syvitski JPM, Kettner AJ, Overeem I, Hutton EWH, Hannon MT, Brakenridge GR, Day J, Vörösmarty C, Saito Y, Giosan L et al (2009) Sinking deltas due to human activities. Nat Geosci 2(10):681–686
7. Stanley DJ, Warne AG (1993) Nile Delta: recent geological evolution and human impact. Science 260(5108):628–634
8. CRI/UNESCO/UNDP (1978) Coastal protection studies. Final Technical Report, Paris, 1
9. Frihy OE, Khafagy AA (1991) Climate and induced changes in relation to shoreline migration trends at the Nile delta promontories, Egypt. Catena 18(2):197–211
10. Tran TT (2011) Morphodynamics of seasonally closed coastal inlets at the central coast of Vietnam. PhD, Delft University of Technology
11. Hayes MO (1975) Morphology of sand accumulation in estuaries: an introduction to the symposium. Estuar Res 2:3–22
12. Hayes MO (1979) Barrier island morphology as a function of tidal and wave regime. Barrier Islands 1:27
13. FitzGerald DM (1996) Geomorphic variability and morphologic and sedimentologic controls on tidal inlets. J Coast Res (23):47–71
14. Hume TM, Herdendorf CE (1992) Factors controlling tidal inlet characteristics on low drift coasts. J Coast Res 355–375
15. Bruun P, Gerritsen F (1960) Stability of coastal inlets. Coast Eng Proc 1(7):23
16. Murtagh J, Nelson H (1993) Narrabeen lagoon entrance sand fluidisation scheme pilot study. In: 11th Australasian conference on coastal and ocean engineering: coastal engineering a partnership with nature; Preprints of Papers, p 609
17. Cooper JAG (1994) Sedimentary processes in the river-dominated Mvoti estuary, South Africa. Geomorphology 9(4):271–300
18. Ranasinghe R, Pattiaratchi C, Masselink G (1999) A morphodynamic model to simulate the seasonal closure of tidal inlets. Coast Eng 37(1):1–36
19. FitzGerald DM (1988) Shoreline erosional-depositional processes associated with tidal inlets. In: Hydrodynamics and sediment dynamics of tidal inlets. Springer, pp 186–225
20. Restrepo JD, Kjerfve B, Correa ID, González J (2002) Morphodynamics of a high discharge tropical delta, San Juan River, Pacific coast of Colombia. Mar Geol 192(4):355–381
21. Hood WG (2010) Delta distributary dynamics in the Skagit River Delta (Washington, USA): extending, testing, and applying avulsion theory in a tidal system. Geomorphology 123 (1–2):154–164
22. Van Rijn LC (2005) Estuarine and coastal sedimentation problems. Int J Sediment Res 20 (1):39–51
23. Van Rijn LC (2004) Estuarine and coastal sedimentation problems. In: Proceedings of the ninth international symposium on river sedimentation, pp 105–120
24. Douglass SL (2002) Saving America's beaches: the causes of and solutions to beach erosion. World Sci Adv Ser Ocean Eng 19
25. van der Spek AJF (1997) Tidal asymmetry and long-term evolution of Holocene tidal basins in The Netherlands: simulation of palaeo-tides in the Schelde estuary. Mar Geol 141(1–4):71–90
26. Zhang J-M, Zhang JH, Wang G, Chen Y (2008) Stability of jetties for channel protection in soft soils at Huanghua Port. Ocean Eng 35(17):1716–1726
27. Kraus NC, Lin L, Smith ER, Heilman DJ, Thomas RC (2008) Long-term structural solution for the mouth of Colorado River Navigation Channel. Texas Coastal and Hydraulics Laboratory, Texas
28. Frihy O, Nasr SM, El Hattab MM, El Raey M (1994) Remote sensing of beach erosion along the Rosetta promontary, northwestern Nile delta, Egypt. Int J Remote Sens 15(8):1649–1660

29. Frihy OE (2001) The necessity of environmental impact assessment (EIA) in implementing coastal projects: lessons learned from the Egyptian Mediterranean Coast. Ocean Coast Manag 44(7–8):489–516
30. Ahmed ASM (2006) Numerical model as a tool to investigate coastal problems in Egypt. In: Tenth international water technology conference, IWTC10, pp 933–944
31. Fanos AM, Khafagy AA, Dean RG (1995) Protective works on the Nile Delta coast. J Coast Res 11(2):516–528
32. Elsayed MAK, Younan NA, Fanos AM, Baghdady KH (2005) Accretion and erosion patterns along Rosetta promontory, Nile Delta coast. J Coast Res 21(3):412–420
33. Elsayed MA, Mahmoud SM (2007) Groins system for shoreline stabilization on the east side of the Rosetta promontory, Nile Delta coast. J Coast Res 23(2):380–387
34. Ahmed ASM (2004) Mathematical model investigation of the suitable countermeasure for the erosion problem at Rosetta promontory, Egypt. In: Proceedings of the sixth international summer symposium, JSCE, Saitama University, no 1991, pp 157–160
35. El Sayed WR, Ali MA, Iskander MM, Fanos M (2007) Evolution of Rosetta promontory during the last 500 years, Nile Delta Coast, Egypt. In: Proceedings of the eight international conference on the Mediterranean Coastal Environment, MEDCOAST 07, 13–17 November 2007, Alexandria, Egypt, vol 1
36. Inman DL, Jenkins SA (1984) The Nile littoral cell and man's impact on the coastal zone of the southeastern Mediterranean. Coast Eng Proc 1(19):1600–1617
37. El Sayed WR, Ali MA, Iskander M, Fanos M (2007) Evolution of Rosetta promontory during the last 500 years, Nile Delta Coast, Egypt. In: Proceedings of the eight international conference on the Mediterranean Coastal Environment, MEDCOAST 07, Alexandria, Egypt, vol 1
38. Masria A, Negm AM, Iskander MM, Saavedra OC (2014) Numerical modeling of coastal nourishment at Rosetta inlet, Egypt. Int Water Technol J
39. Hamza W (2006) The Nile Estuary. Handb Environ Chem 5:149–173
40. El-Sayed MA, Naga WM, Halim Y (1993) Dissolved humic substances in a coastal lagoon of the Nile Delta: distribution, inputs and behaviour. Estuar Coast Shelf Sci 36(5):463–475
41. El-Nady FE, Dowidar NM (1997) Aluminium in the south-eastern Mediterranean waters off the Egyptian coast. Estuar Coast Shelf Sci 45(3):345–355

Part III
Ecosystem, Fish and Fisheries

Ecosystem and Biodiversity in the Nile Basin "Case Study: Lake Nasser"

Mohamed Abdel-Meguid

Abstract The Nile Basin consists of a number of ecological zones between two extreme opposites: the rainforest in the Democratic Republic of Congo (DRC) and the Sahara desert, which receives almost no rain. Some regions receive most or exclusively all of their water from the Nile, while others receive most of the water from rain, or from a combination of water sources. Still, it is the water in the Nile which links the otherwise different ecological zones together. It is the rains in the DRC, Burundi, Rwanda, Tanzania, Kenya, Uganda, and Ethiopia which provide the Nile with water so the river can flow and give life to barren and desert areas in Sudan and Egypt. Some places become drier and experience more droughts, whereas others are more regularly flooded or experience more fluctuations in precipitation patterns. These are overall climatic premises, but there are also human factors. The richness of species depends partly on climate variables such as temperature and rainfall patterns but also on population pressure and human activities and their interaction with the environment.

This chapter describes aspects of environmental issues of ecosystem and biodiversity, endangered species, and threats to biodiversity in the Nile Basin countries to provide a partial illustration of the diversity of ecosystem and the habitat types that exist to support a variety of living organisms. In addition, the chapter describes the case study of Lake Nasser. The study showed that there are several problems that can reduce the species biodiversity in the Nile Basin countries. Some of these problems are, but not limited to, inefficient water use, water pollution, population pressure and land degradation, deforestation and soil loss, over hunting and fishing, and sedimentation. In addition, the study concluded that the main sources of biodiversity degradation in Lake Nasser are development of land, expansion of agricultural land, and disappearance of habitat from excessive grazing or

M. Abdel-Meguid (✉)
Environment and Climate Changes Research Institute, P.O. Box 13621/5, El-Qanater El-Khiria, Egypt
e-mail: Abdel_MeguidM@yahoo.com

A.M. Negm (ed.), *The Nile River*,
Hdb Env Chem (2017) 56: 305–356, DOI 10.1007/698_2016_95,

application of agrochemicals, and also habitats are being polluted and hunting, fishing, and tourism activities are disturbing the natural habitat especially within the shoreline zone.

Keywords Nile Basin countries, Species biodiversity

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1 Introduction

Biodiversity refers to the variety of life on earth. Neither the number of species on earth nor the ecological role of many described species is well known, but it is certain that a variety of life is essential to the functioning of earth's ecosystems. The most widely accepted definition of biodiversity is found in Article 2 of the Convention on Biological Diversity: "Biological diversity' means the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems [1]."

Many of these valuable ecosystems have survived for centuries because of low-intensity land use. However, new practices are a major threat to the conservation of these ecosystems. Human activity (such as urbanization, industrialization, and changing patterns of land and water use due to population growth, conflict, resettlement, and the influence of financial policies and planning processes) influences the variety and composition of life forms within an ecosystem and threatens the habitats, diversity of species, and the nutrient cycle. Threats to biodiversity include habitat loss or alteration, overexploitation, and the introduction of species that alter existing community structures. Habitat loss and degradation are perhaps the most significant threats to biodiversity. The introduction of new (alien) species into geographical areas can occur naturally and has increased dramatically due to human influence. This can threaten biodiversity if the new species competes with indigenous species for resources and alters the food web, habitat, or other aspects of the original community.

Over 99% of all species that have ever existed are now extinct. While extinction is a natural process, scientists have estimated that the current rate of extinction is approximately 100–1,000 times the background (or natural) rate. Extinctions of this magnitude have occurred only five times in earth's history, the most recent being the end of the dinosaur age. Clearly, human influence on biodiversity is significant. The most commonly used system for classifying a species' risk of extinction is the International Union for Conservation of Nature and Natural Resources (IUCN; now known as the World Conservation Union) Red List of Threatened Species. The goals of this program are to [2]:

1. Identify and document those species most in need of conservation attention to reduce global extinction rates.
2. Provide a global index of the state of degeneration of biodiversity.

This system rates each species at risk of extinction as critically endangered (CR), endangered (EN), or vulnerable (VU). Specific criteria for each of these categories are available, but general definitions are as follows:

1. Extinct: There is no reasonable doubt that the last individual has died.
2. Critically endangered: The species faces an extremely high risk of extinction in the wild.
3. Endangered: The species faces a very high risk of extinction in the wild.
4. Vulnerable: The species faces a high risk of extinction in the wild.

World leaders at the 1992 Earth Summit in Rio de Janeiro adopted a strategy for sustainable development. One of the key agreements adopted at the Earth Summit was the Convention on Biological Diversity, which sets out commitments for maintaining earth's ecological foundations during the pursuit of economic development. The objectives of the Convention on Biological Diversity include:

1. The conservation of biological diversity
2. The sustainable use of the components of biological diversity
3. The fair and equitable sharing of the benefits arising from the use of genetic resources

Concerning the Nile Basin, this basin has many diverse ecosystems, including mountainous highlands, freshwater lakes and wetlands, grasslands, tropical rainforest, desert, and the Nile River Delta (Fig. 1).

Tropical rainforests are located along the Nile–Congo divide, in parts of the Lake Plateau, and in southwestern Ethiopia. Heat and copious rainfall produce thick forests with a great variety of tropical trees and plants, including ebony, banana,

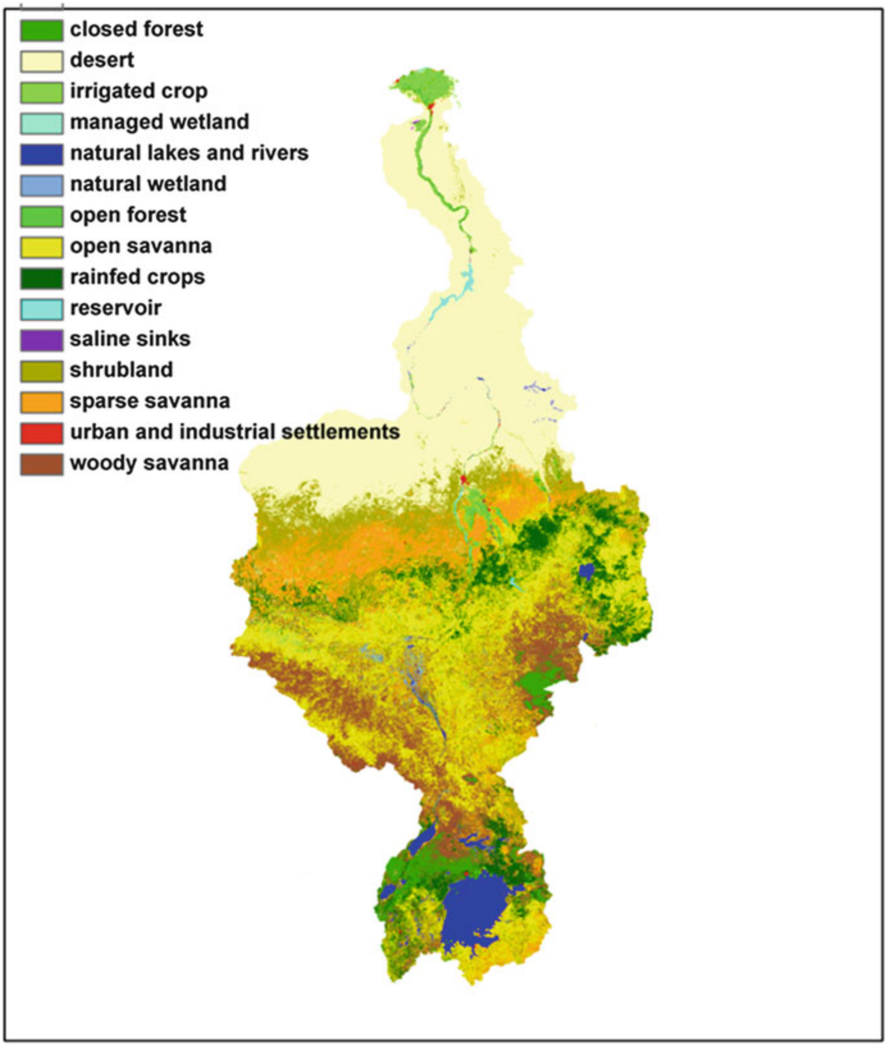

Fig. 1 The Nile Basin land use and water use map. Global Cover Land Cover 2008: the map is produced by European Space Agency. It has 22 land cover global classes, which are defined according to the UN Land Cover Classification System (LCCS) [3]

rubber, bamboo, and coffee shrub. Mixed woodland and grassland (savanna), characterized by a sparse growth of thinly foliaged trees of medium height and a ground covering of grass and perennial herbs, occur in large parts of the Lake Plateau, in parts of the Ethiopian Plateau, in the area that fringes the Blue Nile near Ar-Rusayris, and in the southern Al-Ghazal River region.

On the Sudanese plains, a mixture of thin bush, thorny trees, and open grassland prevails. This area is swampy during the rainy season, particularly in the Sudd region of the south central Sudan. The vegetation there includes papyrus, tall bamboo-like grasses, reed mace ambatch (or turor), water lettuce, a species of convolvulus, and the South American water hyacinth.

North of latitude 10° there occurs a belt of thorny savanna or orchard shrub country characterized by small scattered tree stands, thornbush, and, after rain, grass and herbs. North of this, however, rainfall decreases and the vegetation thins out, so that the countryside is dotted with small thorny shrubs, mostly acacias. From Khartoum, northward there is true desert, with scanty and irregular rainfall and no permanent vegetation at all except for a few stunted shrubs. Grasses and small herbs may be scattered along drainage lines after rainfall, but these die away in a few weeks. In Egypt, the vegetation near the Nile is almost entirely the result of irrigation and cultivation.

In the arid desert zones of the Nile Basin, the biodiversity is low. However, it is high in the lakes, rivers, and other wetlands. The lakes and rivers support 545 species of fish. Notable among those found in the lower Nile system are the Nile perch, the Tilapia, the barbel, several species of catfish, the elephant-snout fish, and the tiger fish, or water leopard. Most of these species and the sardine-like *Haplochromis*, the lungfish, and mudfish are observed as far upstream as Lake Victoria. The common eel penetrates as far south as Khartoum, and the spiny eel is found in Lake Victoria. The Nile crocodile, found in most parts of the river, has not yet penetrated the lakes of the upper Nile Basin.

Other reptiles found in the Nile Basin include the soft-shelled turtle, 3 species of monitor lizard, and some 30 species of snakes, of which more than half are venomous. The hippopotamus can also be observed in the Nile system, especially in the Sudd region.

In addition, the wetlands of the Sudd provide essential habitat to numerous species of birds migrating between Europe and Central Africa, while other wetlands in the basin, including Lake Burullus in Egypt and Yala Swamp in Kenya, provide habitat for globally threatened species.

In the Nile Basin country, land degradation occurs naturally, but it is mainly induced by misuse and/or overuse. Land degradation in the basin is associated with management issues including erosion, salinization, and waterlogging. Other causes of land degradation include soil degradation (surface sealing, sol acidity, structure decline, and fertility decline) and vegetation degradation such as loss of plant biodiversity. Irrigation, particularly in Sudan and Egypt, has been associated with high levels of land degradation associated with waterlogging. In the equatorial lake region, reclaimed swampy land has experienced yield decline after several years of cultivation. Wetlands, mainly swamps and marshes in Rwanda, Burundi, Kenya, Uganda, Ethiopia, and Sudan, continue to experience encroachment by farmers. Encroachment into marginal lakeshore, wetlands, and riverine ecosystems results in modification of the ecosystem, including community structure and/or species composition. Soil erosion in the basin is highly variable in time and space. The main hot spots are in cultivated steep sloping lands in the highlands of Ethiopia, Kenya, Uganda, Rwanda, and Burundi and the overgrazed grassland in Sudan, Ethiopia, and Uganda. Desertification induced by extremes in climate and unsustainable land use practices is becoming a serious problem in southern Sudan, Ethiopia, and Eritrea. The causes of deforestation vary widely, but include high land use and population pressure, cultivation on steep slopes and on river banks, annual crop cultivation, deforestation, bush fires and burning of crop residue, high-intensity storms and high soil erodibility, poor vegetation cover, overgrazing, and highly degraded soils [4].

Although species extinction is part of the natural cycle, the human activities on the Nile Basin countries have accelerated the rate at which species are disappearing. The list of endangered species in the Nile Basin is growing due to a range of causes from overhunting to a loss of habitat. The best source of data on this is the Red List, compiled by the IUCN species program (last modified on Wednesday 11 June 2014). Table 1 summarizes the endangered species by country in the Nile Basin.

This chapter describes a sample of the species biodiversity within the Nile Basin countries and Lake Nasser (case study) and considers some of the threats as well as initiatives to conserve biodiversity.

2 Biodiversity in the Nile Basin Countries

2.1 Burundi

2.1.1 Important Environmental Issues

Due to its geographical position in the heart of Africa, temperate climate, and attractive landscapes, Burundi is referred to as the "Switzerland of Africa." The climate varies from temperate in the mountainous area of the peak Congo–Nile to tropical, which is found in the central plateau and its surrounding hills and the depressions in the eastern and northeastern part of Burundi.

At the root of Burundi's environmental threats is one of the highest population densities in Africa: approximately 405.5 people per km^2 as of February 2016 [5]. Land pressure has led individuals to cultivate on hillsides, where soils are shallow, low in fertility, and easily affected by erosion. Cultivation is also spreading to low-lying wetlands, where constructed drainage systems accompanied by siltation from surrounding hillsides are destroying many of these ecologically valuable areas. Additionally, much deforestation of the original forest covers occurs due to intensification of agriculture as well as timber and fuel wood harvesting. Little of Burundi's native fauna or flora remain today; species such as elephants and gorillas have become locally extinct. The remaining habitats and natural flora are largely in the national parks of Kibira and Ruvubu, and possibly in some pockets of forest reserves scattered throughout the country, which have not benefited from continuous or effective management over the last decade.

Roughly 91% of the total land area is utilized for crops or livestock. Intensive cultivation has led to severe soil erosion on Burundi's naturally steep terrain.

Table 1 Endangered species by country in the Nile Basin

Country	Mammal	Bird	Reptile	Amphibian	Fish	Mollusk	Other inverts	Plants	Total
Burundi	16	30	0	7	23	5	5	1	87
Congo, D. R.	45	62	3	16	32	17	12	67	254
Egypt	14	30	9	0	38	0	132	2	225
Eritrea	7	24	1	0	24	0	148	3	207
Ethiopia	44	42	1	11	3	3	11	21	136
Kenya	44	55	2	8	81	19	151	103	463
Rwanda	25	32	0	9	9	0	2	2	79
Sudan	23	33	2	0	22	0	130	16	226
Tanzania	52	71	3	52	161	22	161	240	762
Uganda	37	45	0	7	62	11	16	39	217

Source: compiled and computed from 2009 IUCN Red List of Threatened Species (last modified on Wednesday 11 June 2014)

Seventy-six percent of land is considered severely degraded. In addition, Burundi losses about 5.2% of its forest cover annually between 2000 and 2005 [6, 7].

Forests and other wooded land suffer from deforestation. Forest area decreased from 1.011 million hectares in 1990 to 0.847 million hectares in 2005 [8]. Such deforestation has influenced Burundi's species biodiversity and ecosystems. It has contributed to the extirpation of both gorillas and elephants. In addition, soil erosion from deforestation has caused siltation of rivers, lakes, and wetlands, threatening both aquatic ecosystems and freshwater supplies.

Moreover, Burundi suffers from bacteriological pollution from animal waste, organic pollution due to waste effluent from coffee processing plants, and industrial pollution due to chemical fertilizers such as nitrates, phosphates, and pesticides. Some of the causes of pollution are high demographic density, lack of latrines and waste dumping, and mining activities resulting in discharge of heavy metals and arsenic, especially in River Akanyaru's tributary, Nowgere [9].

2.1.2 Critical Sites

Kibira National Park to the northwest (comprising a small region of montane rainforest adjacent to Nyungwe Forest National Park in Rwanda) is home to ten primate species, among them chimpanzees. In addition, a large variety of birds can be observed in Kibira National Park.

Ruvubu National Park to the northeast along the Ruvubu River Valley teems with buffalo, antelope, red colobus monkeys, over 400 species of birds, hippos, and crocodiles.

Freshwater resources in Burundi include three large lakes (Tanganyika, Cohoha, and Rweru); several significant rivers and streams, which feed into the Nile and Congo River Basins; and numerous marshes and wetlands. Lake Tanganyika is particularly important for its large number of endemic fish species, especially cichlids.

Rusizi National Park (near Katumba) is located some 25 km from Bujumbura, along the Congo border. It is a wetland environment that provides a habitat for hippos, crocodiles, sitatungas (aquatic antelopes), and a wide variety of birds.

The main forests are Congo–Nile Ridge (Kibira); Kigwena Natural Forest, located on the shores of Lake Tanganyika; Bururi Rumonge–Vyanda Natural Forest; and the forest of Nyakazu and Mwishanga.

The Rusizi Managed Nature Reserve is an interesting area of floodplain habitats, although most of the large mammals have died out. It remains important for other species.

Kirundo, 200 km from Bujumbura in the northeast of Burundi, is a region of extensive depressions dotted with many lakes abounding in bird life, including Cohoha, Rweru and Rwihinda, Kacamirinda, and Kanzigiri.

2.1.3 Endangered Species

The geographical structure of Burundi and the microclimates within the country provide for a diversity of vegetation. The fauna is also quite rich and comprises antelopes, hares, buffalo, and other animals. There are crocodiles and hippopotami in Lake Tanganyika. Land pressure is a considerable risk causing extinctions of certain species because the remaining habitats are not large enough to support viable populations. Eighty-seven species have been listed as endangered [2] as shown in Table 1.

2.1.4 Threats to Biodiversity

1. Owing to the high human population density in Burundi, most of the natural habitats are disturbed, and those that survive are often small and fragmented.
2. Land clearing for cultivation is the greatest cause of deforestation in Burundi.
3. Poorly protected and managed of the wetlands.
4. Some protected areas are in danger because they contain human settlements.
5. There is a continuing threat to the fish fauna (especially in Lake Tanganyika) from pollution, overfishing, and the potential introduction of alien fish species.
6. The ongoing civil conflict negatively influences biodiversity.

2.2 The Democratic Republic of Congo (DRC)

2.2.1 Important Environmental Issues

About 45% of the DRC contains primary rainforest, which provides a refuge for several large mammal species driven to extinction in other African countries. Overall, the country has more than 11,000 species of plants, 450 mammals, 1,150 birds, 300 reptiles, and 200 amphibians. Home to the greatest extent of tropical rainforest is Africa; deforestation caused by agricultural activity and the national dependence on fuel wood and mining are the main evident.

The forests and savannahs of DRC support abundant and rare wildlife [10]. The DRC is home to more types of great apes than any other country on earth, including the critically endangered lowland eastern gorilla and the bonobo. Poaching is an issue throughout Central Africa, although the situation is perhaps most severe in the DRC, where armed conflict, widespread poverty, and illegal mining all contribute to the problem.

The DRC is nearly 60% forested and alone accounts for one-fifth of Africa's total forest area. Much of this forest is relatively undisturbed, making it an ecosystem of global importance. However, many areas are threatened by fuel wood collection, agriculture, and logging. Because of these activities, forest and other wooded land in the DRC decreased from 223,807 million hectares in 1990 to

216,886 million hectares in 2005. DRC has lost nearly 7 million hectares of forest since 1990 [11].

The DRC possesses substantial mineral resources, including diamonds, gold, copper, and coltan. Mining of these various deposits increases human activity in forest interiors, causing substantial degradation to surrounding ecosystems and increasing exploitation of forest resources such as wildlife and timber. Coltan mining in Kahuzi–Biega National Park, for example, has been implicated in the precipitous decline of the lowland gorilla population (less than 1,000 gorilla) [12].

2.2.2 Critical Sites

The most extensive terrestrial ecoregion in western DRC is the western Congolian forest-savanna mosaic with small areas of Atlantic Equatorial coastal forests and Central African mangroves near the coast. Aquatic ecoregions are the lower Congo, the lower Congo Rapids, Malebo Pool, and the Gulf of Guinea South Marine Ecoregion.

The area around Kinshasa and extending westward to the coast has varied topography and vegetation and a high human footprint associated with high population density, intensive agriculture, industries including oil and hydropower, port facilities, and relatively good roads and communications. Protected areas near the coast are the Mangrove National Park and the Luki Biosphere Reserve. Included in the former are most of the mangrove swamps on the DRC side of the Congo River and Estuary, and the sandy beaches along the coast, important for marine turtle nesting, have partial protection. Luki Reserve, although small, protects about 8,000 ha of Mayombe Forest, important for plant conservation [13].

Along with the eastern mountains and the Katanga mining area, western Congo has the largest human footprint; biodiversity loss and forest degradation are more severe here than in less disturbed areas. Problems include both species extinction and loss of diversity within landscapes, including diversity useful to communities [13].

The Congo River and Estuary below Matadi in the Bas Congo have high richness of birds including pelicans, the black-crowned crane, herons, and egrets and are key staging, feeding, and breeding areas for migratory water bird species. In addition, the area harbors populations of manatees and dwarf buffalo.

The Aruwimi-Ituri-Uele wetland (Oriental Province) on the Ituri River is a key site for migratory birds and a feeding or resting ground for many species.

The moist forest is the vast rainforest that covers the uplands and swamps along both sides of the Congo River, including the forests in the big bend. This area is very high in biodiversity and endemism, but it contains also poorly explored and might even yield new species of larger mammal, like the new *Cercopithecus* monkey, resembling the endangered owl-faced monkey, recently discovered in the Tshuapa–Lomami–Lualaba area. The forest is very important for great apes, bonobos, chimpanzees, and gorillas, listed by the World Conservation Union

(IUCN) as critically endangered or endangered. Okapis are endemic to the eastern part of the moist forest, and populations of forest elephants continue to decline [13].

Dry deciduous forest (miombo), widespread in eastern and southern Africa, is the climax vegetation over much of the southeast DRC and constitutes about 10% of the countries’ total forest cover. The vegetation is a large-scale mosaic of forests interspersed with edaphic grasslands, especially on sand or dry ridges, and riparian/wetland vegetation in depressions. Miombo is rich in species, especially plants and birds, and low in endemism, though rare birds occur around the wetlands and rare plants occur on copper-rich soils and elsewhere. Formerly, dry forests were moderately rich in large mammals, with higher densities around wetlands, but populations have been greatly reduced by poaching [13].

The ecoregions southern Congolian forest-savanna and the Kasai aquatic ecoregion cover a large area of about 570,000 km^2 mostly in southern DRC. The southern Congolian forest-savanna mosaic is a blend of forest, woodland, shrubland, and grassland habitats. In DRC, this ecoregion is a plateau that slopes downward from the Angola border and the Katanga upland toward the Congo River and is drained by the large Kasai River and other Congo tributaries. While the forests have only a few known endemic species, they have a rich fauna, including a number of different antelope species and high numbers of African elephants [13].

2.2.3 Endangered Species

In DRC, there are three different classes of ecoregions: terrestrial, freshwater aquatic, and marine, with the first two overlapping because of the extensive freshwater swamps.

In DRC, the forests cover an area of 2 million km^2 which represents roughly half of the high rainforests. The remainder is open forests and woody savannah. Designated parks and conservation areas occupy around 18 million hectares, or 8% of the national territory. DRC contains an estimated 10,000 species of plants, 409 species of mammals, 1,117 species of birds, and 400 species of fish – making it the 5th most biodiverse country on earth [14]. Forest types include the moist evergreen/semi-deciduous forest across the center of the country and extensive dry forest (miombo) in the south. In addition, there are forest/savanna mosaics. The mammal’s category contains most of the highest-profile endangered species. Some species continue to decline because of illegal trade in wildlife products, especially ivory and rhino horn.

In DRC, there are a number of threatened and endangered species across all orders. There are 72 species which are completely protected by law in DRC, though in practice, this protection is very weak, and 234 partially protected species, whose exploitation requires a permit. In DRC, there are 254 endangered species [2] as shown in Table 1.

2.2.4 Threats to Biodiversity

1. Fish introductions can have a major deleterious effect on native fish populations. In addition, the species biodiversity and the fishery productions are also at risk from pollution and overfishing.
2. Agricultural expansion especially in eastern DRC threatens the biodiversity and the richness of fauna and flora.
3. The commercial bush meat trade is the primary cause of wildlife extinction.
4. Industrial mining activities – without adequate safeguards, including the use of biodiversity offsets – will continue to threaten the DRC's forests and biodiversity.
5. Cutting for fuel wood is a major driver of forest degradation around DRC's urban areas.
6. Illegal artisanal logging and cross-border trade are linked to industrial logging concessions.
7. Illegal trade in endangered species continues to have an impact on the DRC's elephant, hippo, and gray parrot populations as well as on important plant species including *Prunus africana* and *Afromosia* spp.

2.3 Egypt

2.3.1 Important Environmental Issues

Egypt is facing increasing water needs, demanded by rapidly growing population, increased urbanization, and higher standards of living. An agricultural policy has further emphasized expanding production in order to feed the growing population. The population is currently increasing by more than one million people a year. With a population of approximately 90 million in 2016, it is expected to increase to 100 million by 2025. The most critical constraint facing Egypt is the growing shortage of water resources accompanied by the deterioration of water quality.

Main sources of biodiversity degradation are development of land, expansion of agricultural land, and disappearance of habitat from excessive grazing or application of agrochemicals, as well as polluted habitats especially the wetland of the Delta area. In addition, hunting, fishing, and tourism activities are disturbing the natural habitat areas.

Habitat loss includes those belonging to mammals like the African lion, raptors, and bird species like geese and ducks, which have lost habitat due to expansion of agricultural land or stockbreeding. In addition, development in coastal areas threatens animals like desert rats. Human-induced pollution has also had negative effect on species biodiversity, i.e., soil pollution and water degradation effects on raptors like lesser kestrel and bird species like white-tailed sea eagles and lesser flamingo. In addition, overhunting and overfishing cause biodiversity degradation. Mammals such as the African lion and fennec fox, and bird species such as duck and snipe, are for game hunting, whereas various birds and sea turtles and fish including gilthead and sandfish are in decrease for hunting for living. Human-caused turmoil from tourism is threatening bird species living in coastal region.

According to the Strategic Foresight Group [9], the Nile waters that pass through Egypt undergo a process of cleansing as they pass through the reservoir of Lake Nasser. However, water quality is still a concern because of agricultural drainage, industrial development, domestic, and wastewater pollution.

Presently, the annual industrial water usage is 5.9 BCM, of which 550 MCM is discharged untreated into the Nile River. There are approximately 125 major industrial plants within the Nile Valley, which contribute to heavy metal loads.

Because of excessive use of fertilizers, estimated at almost 6.5 million tons each year, there are runoff and seepage into surface and groundwater.

In addition, upward seepage of seawater is leading to high salinity levels in the Delta. In the Delta region, the Rosetta Branch receives a higher concentration of organic compounds, nutrients, oil, and grease than the Damietta Branch.

Consisting mostly of hyperarid lands that are highly vulnerable to desertification, Egypt cultivates a very small percentage of its land. Virtually 100% of this irrigated cropland is contributing to annual cereal yields that are the highest in Africa [15]. However, pressures on agricultural land, including urban encroachment, waterlogging and soil salinity, pollution, and erosion from intensive farming have contributed to degradation and exacerbated the land scarcity problem. The estimated production loss from land degradation is about 8% in some areas north and northeast of the Nile Delta [16].

2.3.2 Critical Sites

Of the sources of pollution to the Nile River, discharge of raw sewage, especially in the rural areas, is the most critical. Most waterways receive raw sewage directly from units or sewage-/sludge-emptying trucks.

There are about 24,000 industrial enterprises in Egypt, of which about 700 are major industrial facilities. In general, the majority of heavy industry is concentrated in the Greater Cairo and Alexandria areas. Approximately 387 million m^3 are discharging from industrial effluents to the Nile, its canals, and drains.

Throughout Egypt, the course of irrigation and drainage canals is a total of approximately 55,000 km. Degradation of water quality in the Nile River and associated irrigation and drainage canals is a major issue in Egypt.

Delta drains receive discharge from predominantly untreated or poorly treated wastewater (domestic and industrial), as well as drainage of agricultural areas. Furthermore, the drainage water in the Delta region is becoming more saline; on average, its salinity increased from 2,400 g/m^3 in 1985 to 2,750 g/m^3 in 1995.

Four coastal lagoons fringe the north coast of the Nile Delta area in Egypt: Lake Manzala, Lake Mariout, Lake Edku, and Lake Burullus. One further lake also borders the Mediterranean Sea in the north of Egypt, Lake Bardawil in the Sinai Peninsula. The environmental quality of Lake Bardawil, which is a Ramsar site, is pristine. The other four lakes on the north coast of Egypt, however, suffer from a great deal of environmental pressures.

2.3.3 Endangered Species

Egypt consists of a large desert plateau, interrupted only by the Nile River Valley and Delta, which constitute less than 5% of the nation's territory. Approximately 97% of the population occupies these latter lands; reaching Egypt population density is 87.1 people per km^2 as of February 2016 [17].

The main characteristic for Egypt is the desert and draught; however, Egypt's biodiversity is of global significance for 143 species, because it is located at the juncture of three continents: Europe, Africa, and Asia. It is the home of at least 800 species of nonflowering plants, 2,302 flowering species and subspecies, 116 mammal species, 447 bird species, 109 reptile species, 9 amphibians, and more than 1,000 fish species. Invertebrates are very diverse, for instance, insects vary between 5 and 10 thousand species, more than 200 coral species, 800 mollusks, and more than one thousand crustaceans.

Natural forest distribution is limited in the mountain area of the Gebel Elba, at latitude 22°–22°30′N, and tropical rainforest, mainly composed of acacias and mangrove forest, at the coastal area of the Red Sea. Protectorates of Elba, Ras Mohamed, Nabq, and Abu Galum existed in these areas.

Regarding losses of habitats, there are 225 endangered species in Egypt such as African lion, raptors, and bird species like saker falcon, gray sea eagle, etc. (*Falco cherrug, Haliaeetus albicilla*, etc.); sociable lapwing, *long-billed* curlew, etc. (*Vanellus gregarius*, *Numenius tenuirostris*, etc.); and lesser white-fronted goose, white-headed duck, etc. (*Anser erythropus*, *Oxyura leucocephala*). Also, animals like desert rats are threatened by development in coastal areas. Many species are adversely affected by human-induced pollution, i.e., raptors like lesser kestrel are for soil pollution and bird species like white-tailed sea eagles and lesser flamingo are affected by water degradation. In addition ferruginous duck (*Aythya nyroca*), gray sea eagle (*Haliaeetus albicilla*), and Audouin's gull and white-eyed gull (*Larus audouinii*, *Larus leucophthalmus*) are affected by human disturbances. Table 1 shows the Egyptian endangered species [2].

2.3.4 Threats to Biodiversity

1. Loss or degradation of the habitat is the main concern for decreasing the mammal, bird, fish, and reptile biodiversities.
2. Development in coastal areas threatens some animals like desert rats.
3. Human-induced pollution negatively affects many species, i.e., raptors like lesser kestrel are for soil pollution and water degradation affects bird species like white-tailed sea eagles and lesser flamingo.

4. Mammals such as the African lion and fennec fox, and bird species such as duck and snipe, are for game hunting, whereas various birds and sea turtles and fish including gilthead and sandfish are in decrease for hunting.
5. Human-caused turmoil from tourism is threatening bird species living in coastal regions.
6. Most cultivated agricultural areas are spreading across Nile Valley and Nile Deltas. Almost all of these areas are indigenous habitats and their species have long been replaced by valuable agricultural land.
7. Due to loss and/or contamination of habitat, mammals like shrew, snipes and plovers, geese, and raptors are in decline.
8. Egypt’s coral reefs are attracting millions of international tourists to the region. However, pollution from solid waste and chemical residues from agricultural, industrial, and urban development threaten coastal ecosystems.

2.4 Eritrea

2.4.1 Important Environmental Issues

Historically Eritrea accommodated a wide range of animal species including elephant, hippopotamus, buffalo, giraffe, greater kudu, wild ass, Nubian ibex, waterbuck, lion, leopard, cheetah, and colobus monkey as well as numerous other smaller species. At present, population of these species persists in parts of Eritrea, but they are few in number and threatened [18] because of water stress, population pressure, land degradation, and deforestation.

With only one perennial river and no natural fresh surface water bodies, Eritrea is facing scarcity of water. The country depends on groundwater resources that are regionally limited in both quantity and quality. Agriculture accounts for 95% of all water withdrawals [18]. The percentage of groundwater use in full/partial control schemes was 96.6% or 3,961 ha in year 1993. Area actually irrigated was about 62.5% of the equipped area in year 1993 [20].

Eritrea is at extremely high risk of desertification due to its arid climate and heavy reliance upon agriculture despite limited availability of arable land. Only 6.3% of land is suitable for cultivation and most of this potential has already been exploited [16]. However, continued population growth has forced expansion onto marginal lands and steep slopes. Livestock grazing, which is concentrated predominantly in the semiarid western lowlands, has also exposed soils to water and wind erosion.

Forests account for only 15% of land in Eritrea. The area of forest and other wooded land decreased from 9.2 million hectares in 1990 to 8.8 million hectares in 2005 [21]. Agricultural expansion, deliberately set forest fires, and demand for fuel wood are the main causes of deforestation (about 1 million hectares). Deforested terrain is particularly vulnerable to soil erosion due to torrential and erratic rainfall. Furthermore, deforestation removes valuable habitat for threatened species, including elephant, wild ass, greater kudu, and civet, all of which are in danger of national extirpation.

In the Red Sea, there is a relatively pristine coastal and marine environment because of its low population density. The Red Sea coast and the 350 islands of the Dahlak Archipelago support fertile fishing grounds, with over 1,000 species of fish, 220 species of corals, and 851 km^2 of mangrove forest.

2.4.2 Critical Sites

Eritrea consists of diverse climates and landscapes, from the hot and dry Red Sea coastal plain to temperate central highlands. Dividing the country between semiarid lowlands to the east and west, the highlands range between 1,500 and 2,000 m in altitude and are among the oldest areas cultivated by humans in the world. Sixty-five percent of the population lives in the highlands, although the highlands account for only 19% of the total land surface [19].

Eritrea exhibits a well-distributed, wide variety of natural ecosystems. Extensive grassland systems include *Aristida* grasslands in the west and *Sorghum purpureo-sericeum* grasslands in the southwest which are punctuated by riverine forest and border on large tracts of *Acacia* woodland. The vegetation of the mountainous north is primarily steep, with patches of semidesert and riverine woodland. The south central region hosts several forest systems, including *Acacia* woodland, *Juniperus* forest, and north of Asmara, the last remnant of mixed evergreen tropical forest.

Eritrea's lengthy coastline is a mixture of semidesert and halophytic vegetation with small patches of mangrove forest. Offshore, Eritrea harbors healthy coral reefs as well as over 350 islands, many of which are home to a variety of wildlife species. There have been reported sightings of *Oryx* and gazelle, but these need to be verified. The island system offers sanctuary to endangered species such as the *dugong* (*Dugong dugon*) and the green sea turtle (*Chelonia mydas*). These ecosystems are under pressure, and current protective measures are insufficient to ensure the long-term survival not only of these habitats but also the species that occur therein.

There are three areas of particular interest for forest biodiversity: mixed forest, riverine forest, and the marine environment.

The dense and disturbed highland forest ecosystem is located in the eastern escarpments of Eritrea encompassing 1,001 km^2 [22]. There are two types of forestlands, namely, disturbed *Juniperus* (coniferous) forest and dense and disturbed mixed forest. Both types of land use and land cover units are found in Semenawi and Debubawi Bahri or in the Green Belt, although small highly disturbed patches of juniper groves are found at Abahane, Kohaito, and Soira in the south and Rora Habab in the north [22, 23]. Abehane, Soira, and Rora Habab juniper forests are extremely disturbed and look unstable.

The riverine forests are found mainly in the western lowlands, alongside the Gash, Barka, and Anseba intermittent rivers, encompassing a total area of 1,865 km^2 [22].

The marine environment makes a major contribution to Eritrea's natural heritage and biological diversity. There are many different marine and coastal habitats and ecosystems in Eritrea, such as (1) sabkha, (2) sandy shores, (3) rocky shores and cliffs, (4) intertidal mud flats, (5) mangroves, (6) sea grass beds and macro-algal hard bottoms, (7) coral reefs, (8) open sea, and (9) sea bottom and continental slope.

2.4.3 Endangered Species

In Eritrea, about 49% of the country is rangeland, and approximately 75% of the total population depends on livestock production [24]. The major resources in the rangelands include indigenous grasses and browse plants, water points, and shade provided by vegetation. Environmentally friendly management techniques are missing in the rangelands. However, in most cases, pastoralists do allow large trees to persist in limited numbers as they provide shade for livestock [24]. Only one century ago, forest covered 30% of Eritrea. By 1952, that amount had dwindled to 11%. In 1960, the estimated forest cover was about 5% of the country. Currently, the estimated cover is about 1%, or even less [24, 25]. This is mainly due to agricultural clearance, war, and severe drought in the country. In Eritrea, a variety of natural resources have been declining because of human-made and natural calamities such as drought, deforestation, and prolonged war. Historically, the country accommodated a wide range of wildlife species such as African elephant, hippopotamus, buffalo, giraffe, greater kudu, African wild ass, Nubian ibex, water-buck, lion, leopard, cheetah, colobus monkey, and numerous other smaller species [24]. At present, a few of these species such as African wild ass, Nubian ibex, greater kudu, waterbuck, leopard, and numerous other avifauna species exist in Eritrea, but these populations are small and are considered to be under threat. In Eritrea, there are 207 endangered species [2] as shown in Table 1.

2.4.4 Threats to Biodiversity

1. Excessive collection
2. Forest fire
3. Overgrazing
4. Recurrent droughts
5. Alien avifauna parakeet
6. In coastal zone, sedimentation has been the main threat because of land reclamation on few coastal sites of Massawa. Anchoring is also happening by some fishermen and tourist boats at sea grass beds of the frequently visited islands.
7. In Eritrean Red Sea, many corals are relatively pristine, away from human and economic impact. However, in Massawa, coastal rapid development (such as fisheries infrastructure, fishing operations, aquarium fish collection, tourism, oil pollution from loading and unloading, siltation from land reclamation and road construction) caused negative effects on the habitat structure.

2.5 Ethiopia

2.5.1 Important Environmental Issues

Ethiopia has some of the world's rarest animals and plants, but these are now in danger of disappearing forever due to overuse and loss of natural habitat. Uncontrolled population growth has put ever-increasing pressures on the country's natural resource base.

Desertification, soil erosion, and water pollution are widespread in Ethiopia, particularly in the highlands where the terrain is very steep and where the majority of agricultural production occurs.

Although surface water resources are relatively abundant, they are largely undeveloped and unevenly distributed. Approximately 70% of runoff occurs during June and August, and recurring droughts and erratic rainfall are frequently responsible for widespread food insecurity and significant loss of livestock and crops [26].

In Ethiopia, the main industries are textiles, soft drinks, food, metals, and tannery. However, most of these industries do not have any waste treatment facilities. The notable point pollutants are chromium, hydrogen sulfide, dyes, and caustic soda. The nonpoint pollutants include domestic solid waste and effluents. Additionally, fecal pollution from cattle, pesticide, and fertilizer runoff also contribute significantly [9].

Deforestation and the associated land degradation threaten species biodiversity for both flora and fauna. A loss in biodiversity ultimately implies economic losses to Ethiopia. In addition, the removal of vegetative cover reduces the amount of carbon that can be sequestered from the atmosphere. As the growth stock of Ethiopia's forestry resource base is depleted, its value as a "carbon sink" is reduced. According to Environmental Protection Authority in Ethiopia, 2003 [27], the major causes for the depletion of forest resources are the following:

1. Increases in population and consequent increases in the demand for agricultural land, fuel wood, as well as construction and industrial use
2. Settlements around forest areas
3. Forest fires
4. The expansion of large commercial farms in forest areas
5. The absence of a forest protection and conservation policy
6. The absence of a strong forest administration system capable of arresting the rapidly increasing rate of deforestation as well as controlling and preventing the disruption of the various ecosystems
7. Lack of effort to ensure the participation of communities in forest protection and conservation and the sharing of benefits
8. Failure to clearly demarcate and enforce the boundaries of natural forest reserves

In Ethiopia, up to 400 tons of fertile soil/hectare is annually lost from land with insufficient vegetation cover as well as from land where there is no effective soil conservation. The estimated amount of soil lost annually from wind and erosion is

1.5–1.9 billion tons. About 45% of this soil loss occurs on crop farmlands and 21% occurs on overgrazed rangelands [27].

Furthermore, the wetlands in Ethiopia face threats from demographic pressure with a 2.1% increase in growth rate, overgrazing, soil erosion, and deforestation and urbanization and industrialization [9].

2.5.2 Critical Sites

Ethiopia has many critical sites for biodiversity and several managed protected areas such as Simien Mountains National Park and Awash National Park.

The Awash National Park was established and gazetted in 1966 and 1969, respectively. The park covers at least 756 km^2 of acacia woodland and grassland. Wildlife in this park includes the East African oryx, Soemmerring's gazelle, dik-dik, and the lesser and greater kudus, as well as more than 450 species of native birds.

Abijatta–Shalla National Park is located in the Oromia region, 200 km south of Addis Ababa and east of the Ziway–Shashamane highway. The park contains 887 km^2, including the Rift Valley lakes of Abijatta and Shalla. These two lakes are separated from each other by three kilometers of hilly land. There are more than 450 species of birds in the park that is recognized as an important bird area by Birdlife International [28].

Bale Mountains National Park is in the Oromia region of southeast Ethiopia. The park covers about 2,200 km^2 of the Bale Mountains to the west and southwest of Goba in the Bale Zone. UNESCO's Man and the Biosphere Programme lists the park as a Biosphere Reserve. It is as a World Heritage Site, which is recognized by UNESCO (UNESCO World Heritage) and is currently on the tentative list pending final status [29]. The park is the most important component of the Ethiopian highland biodiversity hotspot as recognized by Conservation International.

Yabello Sanctuary was set up to afford protection to the endemic Swayne's hartebeest.

The Simien Mountains National Park represents an area of spectacular scenic beauty, as well as being of critical importance for a number of rare species.

There are important wildlife resources in the Yabello region of Sidamo Province, including five endemic bird species and a population of the endemic Swayne's hartebeest.

There are important areas for large mammals such as Omo and Mago National Parks and Tama and Chew Bahar Conservation Areas.

All of the lakes in the Rift Valley need some form of conservation measures. Lakes Abijatta and Shalla are included in the Abijatta–Shalla National Park (still ungazetted and inadequately managed). Part of the Lakes Abaya and Chamo and the intervening areas are protected in Nechisar National Park (also still ungazetted). Sufficient projection is lacking for Lakes Zwai, Langano, and Awasa and for wetland habitats in general in the Rift Valley. The Senkelle Swayne's Hartebeest Sanctuary is locating near Lake Awasa.

Very important wildlife populations exist in the Awash River Valley, including populations of the Somali wild ass. Protected areas, all lacking sufficient resources to ensure adequate protection, include Awash National Park, Awash West Conservation Area, Gewane Conservation Area, Yangudi Rassa National Park, and Mille Sardo Wild Ass Reserve (of these, only Awash National Park has been legally gazetted).

Further to the north, in Tigray and southern Eritrea, there is a similar array of species, likewise poorly protected. Likely little action can be taken to remedy this during the current security situation, but this should remain a long-term goal.

The far northern conservation areas of Yob, Nafka, Gash Setit, and Chire are very important for antelopes, though the security situation prevents conservation action.

The Gambella National Park in the west remains ungazetted and adjacent agricultural development threatens it.

2.5.3 Endangered Species

With broad latitudinal and altitudinal ranges, Ethiopia encompasses an extraordinary number of ecological zones, which in turn host rare and endangered species and high rates of endemism.

Species biodiversity in Ethiopia includes 280 mammals, 861 birds, 201 reptiles, and more than 6,000 plants with high rates of endemism [2]. However, the International Union for the Conservation of Nature's (IUCN's) 2014 "Red List" of these species has recorded 136 of endangered species [2] as shown in Table 1.

2.5.4 Threats to Biodiversity

1. Draining for agriculture use.
2. Specifically, the wetlands are often a last destination for pastoralists during the dry season in most parts of the country. However, increases in the livestock population, shortages of fodder, and the simultaneous expansion of agricultural activities have contributed to exacerbating the grazing pressure on wetlands.
3. Deforestation, siltation, soil erosion, and land degradation within a wetland catchment area – the starting cause for an accumulation of silt within the wetland ecosystem.

2.6 Kenya

2.6.1 Important Environmental Issues

Deforestation, soil erosion, and water pollution from urban and industrial wastes are three environmental concerns for Kenya. About 83% of Kenya's land area is vulnerable to drought and desertification. Nevertheless, Kenya's protected areas have increased to over 30 national parks and reserves.

Water pollution in Kenya is caused by point and nonpoint sources such as agricultural practices (salts, fertilizers, and pesticide residues), urbanization, industry, leachates from solid waste tips, and sediments. Additionally, municipal sewerage plants discharge untreated wastewater into watercourses, causing significant health hazards and localized eutrophication. Tanneries, pulp and paper mills, coffee-processing factories, breweries, and sugarcane-processing facilities do not have effective wastewater treatment plants, and their effluents contribute organic loads, heavy metals, and other toxic substances. Although only 8% of Lake Victoria falls into Kenyan territory, tributaries such as Sio, Nzoia, Yala, Nyando, and Mara are already severely polluted [9].

The Nyanza province bordering Lake Victoria is undergoing rapid catchment deterioration due to frequent droughts, deforestation, and old agricultural practices [9]. In the arid and semiarid regions where livestock are grazing, recurring drought exacerbates desertification and threatens the livelihoods of over 3.5 million pastoralists [30].

Widespread deforestation is also contributing to desertification. The estimated deforestation rate is about 5,000 ha/year by 2010 [31].

Concerning the degradation of freshwater ecosystems, Lake Nakuru is suffering from a high load of siltation that comes from surrounding agricultural activities and industrial and domestic effluent from nearby Nakuru Town [32].

Lake Victoria, which accounts for most of Kenya's freshwater fish production, is also threatened. Increased nutrient input from agricultural runoff and the spread of the invasive water hyacinth plant have significantly reduced water quality.

2.6.2 Critical Sites

Kenya's diverse climate ranges from tropical along the Indian Ocean coast to arid in the extreme north. The Great East African Rift Valley bisects highland areas in the center of the country, the location of Africa's second highest peak Mount Kenya. Kenya's dry lands account for 88% of her land surface area. The dry lands are home to a population of approximately 10 million people. About 50 and 70% of livestock and wildlife, respectively, are located in the dry lands [33].

Lake Victoria is the world's second largest freshwater lake, covering an area of 67,850 km^2. Three nations share the waters of the lake (Kenya, Tanzania, and Uganda). Kenya's share is the smallest (3,785 km^2), but is a busy network of waterways between the trading towns and villages, which lie along the shores of the lake.

Ruma National Park was established in 1966. It is a fine place to see roan antelope and Jackson's hartebeest. Oribis, one of the smallest of the antelope family, are also found here and among the predators are lion and cheetah.

The Masai Mara National Reserve is Kenya's finest wildlife sanctuary. The wildlife is abundant and the gentle rolling grasslands ensure that animals are never out of sight. Birds, too, are prolific. Including migrants well over 450 species have been recorded, among them 57 species of birds of prey. The climate is gentle, rarely too hot and well-spread rainfall year round. Between July and October, when the great wildebeest migration is in the Mara, the sensation is unparalleled. The reserve is about 1,510 km^2 having been reduced from 1,672 km^2 in 1984. However, the wildlife is far from being confined within the reserve boundaries and an even larger area, generally referred to as the "dispersal area" extending to north and east of the reserve. Here the great herds of shuffling elephants browse among the rich tree-studded grasslands with an occasional sighting of a solitary and ill-tempered rhino.

Thomson's and Grant's gazelle, topi, and eland and many more species of plains' game offer a rich choice of food for the dominant predators, lion, leopard, and cheetah, which hunt in this pristine wilderness. In the Mara River, hippo can be seen. Seemingly, drowsy crocodile sunbathe on the riverbanks, with its mouth agape, waiting with subtle cunning for prey at which to strike with lightning swiftness. Each year, far south in the great vastness of the Serengeti, the wildebeest raise their dignified but quaint heads, sniff the air, and, as if by one accord, start the long trek to the Kenya border and the Masai Mara. After exhausting the grazing in Tanzania's northern Serengeti, a large number of wildebeest and zebra enter the Masai Mara around the end of June drawn by the sweet grass raised by the long rains of April and May. It is estimated that more than half a million wildebeest enter the Mara and are joined by another 100,000 from the Loita Hills east of the Mara. Driving in the midst of these great herds is an unimaginable experience. The herds draw ravening packs of predators, especially hyenas and lions, and thousands of the lame, laggard, and sick never complete the cycle. More die by drowning or by the teeth of the cunning crocodile while trying to cross the swirling muddy waters of the Mara and Talek rivers. Once the Mara's grass has been devoured and when fresh rain Tanzania has brought forth a new flush there, the herds turn south, heading hundreds of kilometers back to Serengeti and the Ngorongoro plains. There the young grow sufficiently strong to undertake the long march north 6 months later.

Mt Elgon National Reserve, whose peaks reach 4,320 m, lies astride the Kenya–Uganda border. Like most of the other great mountains of East Africa, it represents the remains of an immense volcano. There is no permanent snow on the mountain, but its bleak and craggy peaks are surrounded with the typical afro-alpine vegetation of the high mountains of the equator. Giant groundsel and lobelia grow over the 3,650 m level and for much of the year, everlasting flowers (*Helichrysum* sp.) cover the moorlands. At lower levels giant heath, bamboo, and montane forest prevail and in these areas, there are elephant and plenty of buffalo. Part of the eastern aspect is set aside as the Mt Elgon National Park stretching from the peaks to the boundary of the forest and the heavily cultivated country of the Luhya people. Within the park are a wondrous multitude of wildlife and wild flowers and some exciting oddities, among them the celebrated Kitum and Makingeny caves where elephants probe deep in the dark interiors to sample mineral salts from the cave walls.

Saiwa Swamp National Park (190 ha) is not far from Mount Elgon and only 24 km from Kitale town. Created primarily for the protection of the rare sitatunga antelope, the park is a perfect example of how a small area can survive as a complete ecological entity. The semiaquatic sitatunga relying on a swamp habitat has evolved to survive in such conditions and despite the size of the park seems certain to continue to thrive there. The sitatungas at Saiwa are sufficiently numerous to ensure seeing them. In addition, there are de Brazza, colobus, and vervet monkeys and an exciting variety of birds – some 250 species have been noted in this small area.

Homa Mountain, gaunt and grand, dominates the peninsular. It shelters the small town of Homa Bay. Near Homa Bay are two islands, Rusinga and Mfangano. Rusinga is locally claimed as the burial place of Tom Mboya, a great son of Kenya who was assassinated in Nairobi in 1969.

Kenya is probably the best endowed country in Africa for marine protected areas. These are the Kisite–Mpunguti and Malindi–Watamu protected area complexes and Kiunga Marine National and Biosphere Reserve. Additional protected areas are proposed for Diani and Ras Tenewi. These areas include coral reefs, sea grass beds, dugong and turtle populations, and seabird colonies of international significance, but current levels of protection are limited.

2.6.3 Endangered Species

According to the World Conservation Monitoring Center in the UK, Kenya is among the world’s top 50 countries in terms of species richness; neighboring Tanzania and Uganda also fall into that range. Kenya’s tropical moist mountain forests, East African woodland/savanna areas, and Rift Lakes wetland areas rank it among the highest geographic priorities for USAID’s biodiversity conservation goals, according to the Agency’s Biodiversity Strategy of 1996. Kenya has about 35,000 known species of plants, animals, and microorganisms. This number includes 24,995 described animals’ species. For some taxa, notably birds (1,079 species) and mammals (325 species), the total reported approximate the true species biodiversity. In other taxa, the majority of the species have yet to be formally described. The total number of plant species documented is 6,817 (excluding 229 species of algae), of which the majority are flowering plants.

The most endangered ecosystems in Kenya are forests, terrestrial wildlife habitats, and freshwater and coastal wetlands. Coral reefs will be increasingly threatened if uncontrolled development, existing pollution, and sedimentation from upstream agricultural areas are not slowed. The threat to many of Kenya’s animal and plant species is considered to be high, relative to other countries with similar rankings of species richness and endemism [34]. The following illustrates this point with recent statistics from the IUCN Red Lists, which shows that 463 are endangered [2] as shown in Table 1.

2.6.4 Threats to Biodiversity

1. The habitats and species of the arid northern part of the country, as well as those of the forests and wetlands, are not protected.
2. Agricultural expansion and the need for fuel, wood, and charcoal represent the main cause of deforestation (most notably Arabuko-Sokoke and Kakamega).
3. Wildlife tourism and illegal hunting of large animals threaten the species biodiversity.
4. In many places, the management of protected areas is maintained at a sufficient level.
5. Water management projects are threatening several wetland areas.
6. Fish introductions, pollution, and overfishing are probably having a major deleterious effect on native fish populations, especially in Lake Victoria.
7. Marine areas, particularly coral reefs, are under severe threat from siltation, dynamiting, pollution, over-collection of shells and corals, and tourist pressure.

2.7 Rwanda

2.7.1 Important Environmental Issues

Rwanda is a small, mountainous country located only a few degrees south of the equator, but its high elevation provides for a tropical temperate climate with two rainy and two dry seasons. Rwanda is dominated by the hills and valleys of the central plateau, which are bordered to the east by marshy lowlands, to the north by a chain of volcanoes, and to the west by a mountain system, which forms the boundary between the watersheds of the Nile and Congo River Basins. Surface water is relatively abundant in Rwanda, covering over 8% of the country [35].

Population pressure on land, deforestation, soil erosion and sedimentation, and water pollution are environmental concerns for Rwanda.

Rwanda is the most densely populated country in mainland Africa. Rwanda's current population density is 485.6 per km^2 as of February 2016 [36]. Approximately 80% of the population is rural and engaged in agriculture, placing significant pressure on land resources and biodiversity. Modification and destruction of natural ecosystems for agriculture, and particularly the drainage and reclamation of wetlands, has resulted in the loss of many plant and animal species. An estimated 115 different plant species are threatened with extinction [37].

Rwanda's rich volcanic soils are historically fertile, but population pressure has resulted in overcultivation and expansion onto marginal lands and steep slopes. As of 2003, arable land accounted for over half of the country's surface area and approximately 98% of all potentially cultivatable land in the country [35].

Forests were once extensive throughout Rwanda, but they are now concentrated primarily in the western mountains. The swampy gallery forests that historically characterized the eastern lowlands now exist only in small locations. Despite recording a net increase in overall forest cover since 1990, natural forests remain threatened by human encroachment and high dependence on fuel wood and charcoal [37].

Nyungwe National Park is the largest tropical mountain forest in Africa, covering over 1,000 km^2 of rainforest, bamboo, grassland, swamps, and bogs. It harbors 13 different primate species, 62 Albertine Rift endemic species, and one of the largest surviving populations of chimpanzees [38]. Buffalo and elephants are extirpated due to human encroachment and illegal poaching, and fires started by honey collectors have damaged large tracks of forest.

Concerning the water pollution, the main sources of water pollution are domestic, commercial, industrial, agricultural activities, water hyacinth, and mismanagement of wetlands. Due to increased population, unsustainable agricultural practices, and inadequate sanitation facilities, there is an extensive use of fertilizers and pesticides. In addition, wastewater from rural towns and villages that contain fecal pollution is left untreated, giving rise to waterborne diseases [9].

2.7.2 Critical Sites

Rwanda is a small country with a high human population density, and yet it contains a remarkable variety of different habitats and species. The largest area of natural habitat in the country is the Akagera National Park and the contiguous Mutara Hunting Reserve. This area includes several types of savanna woodland, large swamps, and lakes and is the most important area for large mammals in the country.

The country has several areas of lakes and swamps (including high-altitude swamps in the mountains and papyrus swamps at lower altitudes). Important sites are Lake Kivu, Lake Luhondo, Lake Bulera, and the Akagera, Akanyaru, Nyabarongo, Rugezi, and Mulindo Swamps. These wetlands are under severe threat and are in need of appropriate protection, including new protected areas and sustainable use or better rural development programs. A few swamps are protected in the Volcanoes National Park and the Nyungwe Forest Reserve, but the Kamiranzovu Swamp (in Nyungwe) is threatened by mining [39].

The Kivu Belt Region is one of the most attractive regions in Rwanda. The driving force behind the dynamic increase in tourism in this area is, so far, largely the gorilla tourism. The national parks (mainly Nyungwe National Park) are another main attraction in the area.

The Volcanoes National Park is home to 245 species of plants, including 17 dominant ones of which 13 are internationally protected orchidaceous, 115 species of mammals, 185 species of birds, 27 species of reptiles and amphibians, and 33 species of invertebrates [39].

The Nyungwe Forest Reserve includes some of the most extensive areas of mountain forest in Africa. In this forest, there are more than 1,200 plant species among which are found at least 50 species of fodder and 133 species of orchids. More than 250 wood species have been identified, with more than 275 species of birds, 24 of which are endemic. Thirteen types of primates have been identified, representing 1/5 of Africa's primate species among which is the most threatened, namely, the monkey with an oval face (*Cercopithecus hamlyni*) and the golden monkey (*Cercopithecus mitis* kandti). Nyungwe has one of the remaining biggest populations of chimpanzees of the east (*Pan troglodytes* schweinfurthii). The Angola colobus (*Colobus angolensis*) is generally found in stable groups of between 300 and 400 individuals [39].

In the Akagera National Park, the plant formations are quite diversified. They shelter more than 900 species of plants, including 60 internationally protected orchids. The Acacia Senegal is generally dominant. In the more arid zones of the Akagera National Park, the vegetation tends toward a combination of Acacia–Commiphora, whereas in the wetter areas, Acacia Senegal tends to be replaced by *Acacia polyacantha* and *Acacia sieberiana*. Grassy savannas consist mainly of *Themeda*, *Hyparrhenia*, S*porobolus*, and *Bothriochloa*. The fauna constitutes the park's major attraction. It comprises 47 species of big mammals, more than 500 species of birds, 9 species of amphibians, and 23 species of reptiles.

The lakes of the Akagera National Park are quite rich in biodiversity: the phytoplankton consists mainly of Chlorophyceae, Cyanophyceae, and Diatomophyceae. The floras are mainly dominated by *Cyperus, Phragmites, Phoenix, Potamogeton, Aeschynomene, Thelypteris*, etc. Water hyacinth (*Eicchornia crassipes*) is present and has started covering big areas of the lakes, representing a threat to their biological diversity.

The desert alpine zone (above 3,500 m) is composed solely of lichens and mosses. In addition to the gorillas, the Volcanoes National Park afromontagne forests contain elephants, buffalo, several primates, and other mammals; *Rana angolensis*, *Chamaeleo rudis*, and *Leptosiaphos graueri* are endangered. Overall, the flora and fauna inventory of the park includes

- 245 plant species, and of these, 13 species of orchids are internationally protected
- 115 mammal species
- 187 bird species
- 27 species of reptiles and amphibians
- 33 arthropod species [40].

2.7.3 Endangered Species

Despite its territorial small size, Rwanda is covered by diversified ecosystems: natural ecosystems consisting of mountain rainforests, gallery forests, savannas, wetlands, and aquatic lands and ecosystems that have been altered by man's activities consisting of deforestation and cultivated areas. All these ecosystems accommodate a flora and fauna wealth. Rwanda’s 26,338 km^2 is covered predominantly by mixed cropland/natural vegetation (47%), followed by savannah (32%), forests (12%), and water and wetlands (8%) [40].

Rwanda shelters 2,150 species of plants, 151 different types of mammal species, and 670 different birds [37]. Deforestation and conversion of natural habitats to agricultural systems in the last three decades has caused a loss of variability across its entire ecosystems. The flora comprises hundreds of higher and lower plant species. Some of them have been domesticated for years and are today the basis of human diet; others are meant for commercial and medical uses. In Rwanda, there are 79 endangered species [2] as shown in Table 1.

2.7.4 Threats to Biodiversity

1. Population pressure on biodiversity resources and protected areas.
2. Wetlands outside the main reserves are poorly protected and managed. The important biological resources in these ecosystems could easily be lost through clearance and overuse.
3. Kamiranzovu Swamp is threatened by mining.
4. Agricultural inefficiencies and soil erosion.
5. Some protected areas are suffering from poaching of large mammals, in particular Akagera National Park and the Nyungwe Forest Reserve.
6. Montane forest clearance has been serious in some areas, and the most importance sites have not been given adequate conservation status.
7. There is a potential threat to populations of endemic fish from the introduction of alien fish species, as well as from overfishing and pollution.

2.8 South Sudan

2.8.1 Important Environmental Issues

Sudan descended into civil war in 1983. In 2005, after 22 years of war between the National Congress Party (NCP) in the north and the Sudanese People’s Liberation Army (SPLA) in the south, the parties signed the Comprehensive Peace Agreement (CPA), putting an end to Africa’s longest-running conflict. In 2011, the Republic of South Sudan officially became an independent nation. The armed conflict has severely affected the lives of communities in and around protected areas in South Sudan and, as such, has resulted in a major assault on the country’s wildlife and their habitats. Hunting played an important role in human survival during the war and, as a result, uncontrolled and unsustainable hunting decimated wildlife populations [41].

Population pressure on land, hunting, deforestation, and water pollution are environmental concerns for South Sudan.

2.8.2 Critical Sites

The wildebeest migration in South Sudan is one of the biggest animal migrations in the world and has been described as more spectacular than other migrations on the African continent. This amazing discovery in the Boma region of Eastern Equatoria and Jonglei states has been attracting all sorts of visitors. Furthermore, all of South Sudan's animals that fled to neighboring countries during the war are now returning in amazing numbers.

The White Nile is the greatest natural resource in south. The town of Nimule is home to a magnificent waterfall. This waterfall presents an amazing storm of water raging downhill causing a radiant smoke of evaporation.

The Sudd Swamp contains green carpet of water lilies and other water plants, which presents a beautiful and extraordinary view. The Sudd is also believed by the "people of the Nile" to contain some animals that are extinct in the rest of the world. That belief may have truth because the Sudd has been free from any scientific exploration. The Sudd has spectacular scenery, especially with an aerial view of this wonder land.

South Sudan is home to the second largest wildlife migration on the globe, making game and wildlife a huge tourist attraction. South Sudan hosts 5 national parks and 14 game reserves, bringing spectacular and important wildlife populations to Africa such as buffalos, elephants, giraffes, and lions.

Bandingalo was established in 1992. It is located in a wooded area near the White Nile River, in South Sudan's Equatoria region, within the states of Central Equatoria and Eastern Equatoria. It is over 10,000 km^2 in size.

Earth's second largest annual animal migration, involving multiple species of antelope including reedbuck, tiang, and white-eared kob, takes place in the park, which is also home to iconic African mega-fauna like the giraffe. It also contains large marshlands stretching up into Jonglei state. The park supports large bird populations. Though a major wildlife preserve, the park lies within a total oil concession, potentially exposing it to surveying and drilling.

In Bandingalo National Park, it is uncertain which subspecies of giraffe exists in South Sudan. There is debate it could be the Rothchild's, Nubian, or Kordofan subspecies. South Sudan is the intersection of these three subspecies. All three subspecies are low in total population numbers: Kordofan 2,500, Rothchild's 670, and Nubian 250.

On the border with Uganda is Nimule National Park. The Nile River cuts along the eastern border of the park for 48 km. The road from Uganda to Juba cuts along the eastern border of the park next to the Nile. The park has 41,000 ha to protect the white rhino, which is now extinct. The park is the most accessible of South Sudan's parks. Herds of elephant have made the park their home, realizing they are safe in the park.

Elephant, Uganda kob, Lelwel hartebeest, crocodile, duiker, hippo, waterbuck, bushbuck, oribi, leopard, olive baboon, vervet monkey, warthog, and incredible bird life exist in the park.

Boma National Park is Africa's largest wildlife reserve. As water sources dry up after the seasonal rains and then again when the seasonal rains return, enormous herds of animals migrate in Boma National Park. It is estimated that the migration is far greater than the famous migration of the Serengeti, where nearly two million animals search for grazing.

In South Sudan, as in the Serengeti, the migration takes place all year; it is a slow movement dependent on the grass and the rains. In March/April/May/June, the animals are moving from north to south and west to east, from the Sudd floodplains and Bandingilo National Park, back into Boma National Park and Ethiopia, because the rains will have started. In November/December/January, the animals move from south to north, east to west as the dry season is well under way, and the animals are searching for grass. In November/December/January, the white-eared kob will be calving as they migrate north into the Sudd floodplain and west into Bandingalo National Park. The major migrating species involved are white-eared kob antelope, tiang antelope, and Mongalla gazelle. Prior to the war with the north, there were huge herds of zebra, and these animals were considerably reduced in number. A 2008 survey estimated that there were 6,850 elephants in the park and surrounding area adjacent to the park. The elephants and zebra also migrate with the water and grass seasons.

The Zeraf Game Reserve protects most of the central part of the Sudd wetland at a size of 970,000 ha or 9,700 km^2 and was set aside in the year 1939. The game reserve is important in protecting populations of Nile lechwe antelope, sitatunga antelope, and hippopotamus, not to mention the enormous numbers of migrating birds.

A large portion of this reserve is on Zeraf Island, which floods every wet season. The Bahr el Zeraf River bound the island on the west by the White Nile and on the east.

Mount Kinyeti is the highest peak in South Sudan. Located in the Imatong Mountains in Ikotos county of Eastern Equatoria state, near the Ugandan border, Kinyeti has an elevation of 3,187 m above sea level. The groups of high mountains that contain Kinyeti, extending to the border with Uganda, are sometimes called the Lomariti or Lolobai mountains. The lower parts of the mountain were covered with lush forest. The most important montane forests in Sudan are in the Imatong Mountains in the extreme south. The natural forests are under threat from continued expansion of tea and forestry plantations. Other areas of mountain forest exist in the south in the Didinga and Dongotona Mountains (although these have been degraded by burning) and in the proposed Boma National Park in the southeast.

2.8.3 Endangered Species

South Sudan embraces diverse biological resources, which represent an important national asset and heritage. The Forest National Corporation (FNC) estimates that, after separation of South Sudan, forests cover about 11.60% of the total area, while agricultural land 13.70%, rangelands 26.40%, and water bodies 0.17%. Data of South Sudan's biodiversity is limited. However, some recent efforts aim to fill the gaps. There are 1,013 species of birds in South Sudan, which represent more than any country in the world [42].

The following list includes all mammals, which represent critically endangered (CR), endangered (EN), or vulnerable (VU) in the 2004 IUCN Red List of Threatened Animals [42].

1. Critically endangered
   - Addax (*Addax nasomaculatus*)
   - African wild ass (*Equus africanus*)
   - Burton's gerbil (*Gerbillus burtoni*) (endemic to Sudan)
   - Four-spotted gerbil (*Gerbillus quadrimaculatus*) (endemic to Sudan)
   - Lowe's gerbil (*Gerbillus lowei*) (endemic to Sudan)
   - Principal gerbil (*Gerbillus)*
2. Endangered
   - Chimpanzee (*Pan troglodytes*)
   - Dama gazelle (*Gazella dama*)
   - Giant African Water Shrew (*Potamogale velox*)
   - Grevy's zebra (*Equus grevyi*)
   - Nubian ibex (*Capra nubiana*)
   - Slender-horned gazelle (*Gazella leptoceros*)
   - Wild dog (*Lycaon pictus*)
3. Vulnerable
   - African elephant (*Loxodonta africana*)
   - Barbary sheep (*Ammotragus lervia*)
   - Cheetah (*Acinonyx jubatus*)
   - Desert pipistrelle (Bat) (*Pipistrellus ariel*)
   - Dorcas gazelle (*Gazella dorcas*)
   - Dugong (*Dugong dugon*)
   - Large-eared free-tailed bat (*Otomops martiensseni*)
   - Lesser horseshoe bat (*Rhinolophus hipposideros*)
   - Lion (*Panthera leo*)
   - Red-fronted gazelle (*Gazella rufifrons*)
   - Soemmerring's gazelle (*Gazella soemmerringii*)
   - Spotted-necked otter (*Lutra maculicollis*)
   - Tomb bat (*Taphozous hamiltoni*)

2.8.4 Threats to Biodiversity

1. The management of the protected areas in the country's south has become very difficult to maintain under conditions of civil war, and severe poaching of large mammals with some extinctions likely if the situation does not improve. Inevitably, encroachment has also occurred in some areas, particularly Juba and Kidepo.
2. Overgrazing by livestock has become a major problem in many areas, leading to severe environmental degradation.
3. Disease is potentially an increasing threat. Rinderpest is endemic in country and all susceptible ungulates are at risk.

2.9 Sudan

2.9.1 Important Environmental Issues

Sudan extends over three major climatic zones: the Saharan north, the Sahelian center, and the equatorial south. The population is concentrated largely along the Nile River and its tributaries, where soil fertility and agricultural productivity are high. Rainfall is widely variable throughout the country, ranging from only 25 mm per year in the dry arid north to over 1,600 mm per year in the tropical rainforests of the south [43]. There has been a southward shift ranging from 50 to 200 km of the boundary between semidesert and desert. This boundary is expected to continue to move southward due to declining precipitation.

Sudan faces a number of critical environmental challenges, including land degradation, deforestation, and the impacts of climate change.

In 1974, Sudan passed an act on the application of pesticides; this act was updated in 1994. Unfortunately, the law is not followed by small and poor farmers, who often cause incidents of pollution due to unsafe application of pesticides. Several parts of the country have serious water quality problems; for instance, the Gezira region, Lake Nubia, and eastern and western parts of Sudan. Additionally, urbanization in cities like Khartoum and Wad Medani enhance pollution via sewage [9].

In the agricultural areas surrounding the Nile River, the population density is 21.8 per km^2 as of February 2016 [44]. Sudan is a land of relatively fertile soils and it has the second largest irrigated area in Africa, which accounts for 11% of cultivated area and over half of all production [43]. However, poor cultivation practices as well as overgrazing have led to pollution and land degradation. Resulting soil erosion has already consumed nearly one-fifth of the storage capacity in the country's four primary dams and damaged irrigation canals. Reduced irrigation capacity has decreased production by up to 40% in some areas [43].

Growing demand for fuel wood and agricultural encroachment contribute to a deforestation rate of nearly 1% per year [43].

Inland fisheries account for 90% of the total fish catch in Sudan. Some major reservoirs associated with the Nile and its tributaries, such as the Gebel Aulia and Roseires, are being fished at a level close to 90% of their estimated capacity.

Marine fisheries along Sudan's Red Sea coast, however, are thought to be underexploited, with only half of their estimated potential fish stocks currently being utilized.

2.9.2 Critical Sites

The country has small areas of lowland rainforest in the southwest, and three game reserves protect this habitat: Bangangai, Bire Kpatuos, and Mbarizunga. However, the latter two are tiny, and Bangangai Game Reserve is not currently large enough to contain viable populations of important species.

There are no protected areas in the desert and Sahelian zones of Sudan, which make up half the country, nor are the best sites for such reserves known, in which the species of these arid habitats can be allowed to recover their populations. Such reserves should be established at low altitudes on both the western and eastern sides of the Nile. In addition, protection is needed to conserve the unusual flora and fauna of the Red Sea Hills and of the massifs of Jebel Marra and Jebel Gurgei.

Sudan's marine living resources are partially identified but need further surveying. There are extensive reefs along most of its coastline and these are largely in excellent condition, the Sudanese having little traditional dependence on the sea. The area containing important fringing coral reefs north and south of Port Sudan is under threat from pollution from the expanding port, but there is a proposal for their protection in terms of the Port Sudan Marine National Park.

There is also a proposal for a marine national park on the Sanganeb Atoll (the only atoll in the Red Sea), which has considerable tourism potential. Numerous islands in the Red Sea are probably of importance, but little is known at present. The Suakin Archipelago is known to be important for coral reefs, seabird nesting colonies, and marine turtle nesting beaches, and the Mukawar, Taila, and Mayetib Islands are important for reefs and seabirds [45].

The Red Sea coastal lagoons and sheltered bays "marsas" form natural harbors and fish landing places. The Red Sea has attractive and mostly pristine habitats (particularly coral reefs, mangrove stands, sea grass beds, and associated marine fisheries and biodiversity including sharks, dugongs, turtles, and a variety of sea birds). Sanganeb and Dungonab–Mukawar Island are protected areas with good representation of the Red Sea marine ecosystems [45].

2.9.3 Endangered Species

Wildlife ecosystem in Sudan is composed of biosphere reserves, national parks, game reserves, and sanctuaries. The arid and semiarid habitats of Sudan have always had limited wildlife populations. The various areas in which wildlife are present are derived from a combination of ecological, socioeconomic, historical, and political factors. It should be noted, however, that the boundaries between certain regions are ill defined, and the very limited home range migration of some of the species is within those boundaries. Sudan is endowed with 12 orders of flowering plants out of the 13 found in Africa. In Sudan, there are 3,132 species of flowering plants and 265 species of mammals. Sudan has also 938 of bird species, 105 Nile fish species, and 91 reptile species [45]. In Sudan, there are 226 endangered species [2] as shown in Table 1.

2.9.4 Threats to Biodiversity

1. Overgrazing by livestock has become a major problem in many areas, leading to severe environmental degradation.
2. The northern desert and semidesert areas and marine ecosystems are not included within the protected area system and consequently have been few attempts to safeguard the biological resources of these areas.
3. Disease is potentially an increasing threat. Rinderpest is endemic in the south of the country and all susceptible ungulates are at risk.

2.10 Tanzania

2.10.1 Important Environmental Issues

Tanzania has a total area of 942,800 km^2 of which 881,300 km^2 is land and 61,500 km^2 is inland water. A distinctive feature of Tanzania is the Rift Valley whose form is marked in many places by long, narrow, and deep depressions often filled with lakes. Lake Tanganyika lies in the western rift which continues northward through Lake Kivu. Many rivers flow into the Indian Ocean or the great lakes. However, some of them cease flowing during the dry season, and only the Rufiji, entering the Indian Ocean opposite Mafia Island and the Kagera, flowing into Lake Victoria, is navigable by anything larger than a canoe [46].

Tanzania faces a number of critical environmental challenges, including deforestation and land degradation, water pollution, and population pressure.

In Tanzania, the water quality is influenced by natural factors and human activities. The former comprise high fluoride concentrations and salinity in natural waters. The latter include discharge of municipal and industrial wastewater, runoff from agricultural lands, and erosion encompassing high concentrations of nutrients, pathogens, and BOD and COD levels. Additionally, gold mines in the Lake Victoria Basin contribute to heavy metal pollution.

About 80% of the industries, including agrochemical and chemical industries, breweries, and steel manufacturing industries, are located in the coastal zone of Dar es Salaam. Most of the industries directly or indirectly pollute the Indian Ocean.

Besides damaging aquatic ecosystems, this pollution also leads to higher incidence of waterborne diseases [9].

Forests and woodlands that provide for wildlife habitat, unique natural ecosystems and biological diversity, and water catchments cover about 38% of Tanzania's total land area. However, these forests face deforestation at a rate of between 130,000 and 500,000 ha/year, which results from heavy pressure from agricultural expansion, livestock grazing, wildfires, overexploitation, and unsustainable utilization of wood resources and other human activities, mainly in the general lands [47].

2.10.2 Critical Sites

Tanzania is home to some of Africa's most famous national parks and the majestic Mount Kilimanjaro rising above the Serengeti. Off Pemba and Mafia islands is a whole other kind of natural wonder, one most appreciated by the scuba divers and snorkelers who come here from around the world to experience the coral gardens, colorful fish, and clear waters.

One of the most frequented attractions in Tanzania Mount Kilimanjaro National Park is home to Africa's highest mountain peak. Unlike other parks in northern Tanzania, this one is not visited for the wildlife but for the chance to greatly admire this majestic snow-capped mountain and, for many, to climb to the summit. The mountain rises from farmland on the lower level to rainforest and alpine meadow and then barren lunar landscape at the peaks. The slopes of the rainforest are home to buffaloes, leopards, monkeys, elephants, and eland. The alpine zone is where bird watchers will find an abundance of birds of prey.

Serengeti National Park is a vast treeless plain with thousands, even millions of animals searching for fresh grasslands. The best months for wildlife viewing are between December and June. The wet season is from March to May, with the coldest period from June to October. The annual migration of millions of zebra and wildebeest takes place in May or early June. Large herds of antelope as well as lion, leopard, cheetah, hyena, bat-eared fox, hunting dog, and jackal are also found in Serengeti National Park. Nearly 500 species of birds have been recorded on the Serengeti.

The Zanzibar archipelago consists of the islands of Zanzibar and Pemba. The island of Zanzibar is also called Unguja. This island has some of the best beaches in the world.

Located between the Serengeti and Lake Manyara, the Ngorongoro Conservation Area is home to the famous volcanic Ngorongoro Crater and one of Tanzania's most popular wildlife viewing areas. This huge volcanic crater has a permanent supply of water, which draws all kinds of animals who stay in this area rather than migrating. This important archeological site has revealed ancient skull and bone fragments that have delivered critical information about early humankind.

The Ngorongoro Crater is the largest intact ancient caldera in the world, nearly three million years old. The Ngorongoro volcano was one of the world's tallest mountains before it exploded and collapsed. Thousands of wild game can be seen on the crater floor, including lions, elephants, rhinos, Thomson's gazelles, and buffaloes, but wildebeests and zebras account for over half of the animals that call the Ngorongoro Crater home. Bird watching is superb, especially around Lake Magadi, which attracts flocks of flamingoes to the shallows. Hippos are content to submerge themselves during the day and then graze in the nearby grass in the evening.

The Olduvai Gorge is an archeological site situated on a series of fault lines, where centuries of erosion have revealed fossils and remnants of early humankind.

Lake Manyara National Park is comprised of forest, woodland, grasslands, and swamps. Two-thirds of the park is covered by water and Lake Manyara is host to thousands of flamingoes, at certain times of year, as well as other diverse bird lives. The highlight of Lake Manyara Park is the large population of elephants, tree-climbing lions, and hippos that can be observed at a much closer range than in other parks. This park is also home to the largest concentration of baboons in the world.

Mafia Island draws divers and snorkelers from around the world to the undersea world protected by the Mafia Island Marine Park. The best months for diving are October to March on Mafia Island, while March and April are months of heavy rain. Mafia Island Marine Park has excellent coral gardens, an abundant variety of fish, and a relaxed diving atmosphere. Countless birds and over 400 species of fish can be seen in the area. Mafia Island is also a traditional breeding site for the green turtles, which are unfortunately close to extinction. Mafia is also a desirable location for deep-sea fishing, especially tuna, marlin, sailfish, and other big-game fish.

Tarangire National Park was established in 1970. During the dry season, Tarangire National Park has one of the highest concentrations of migratory wildlife. Wildebeest, zebra, buffalo, impala, gazelle, hartebeest, and eland crowd the lagoons. One of the most noticeable highlights of Tarangire National Park is the baobab trees that dot the grassy landscape. The park is excellent for bird watching, with more than 300 species recorded in Tarangire. These species include buzzards, vultures, herons, storks, kites, falcons, and eagles.

Pemba Island is the northernmost island in the Zanzibar archipelago. Around Pemba are many desert islands and some of the best scuba diving in the Indian Ocean, with visibility that is unparalleled. Lush coral gardens, colorful sponges, and sea fans are all found in the underwater haven. Pemba is a major world clove producer and is also well known for the juju traditions of medicine and magic. People come from throughout East Africa to learn from the voodoo and traditional healers or seek a cure.

Selous is the largest game reserve in Africa. Established in 1922, it covers 5% of Tanzania's total area. The southern area is a forbidden zone that is undeveloped and heavily forested and contains a series of steep cliffs. This area of the Selous Game Reserve has large open grassland, woodlands, rivers, hills, and plains.

The Rufiji River bisects the Selous Game Reserve and has the largest catchment area of any river in East Africa. The river is an important feature of the reserve providing the opportunity to watch the diverse water-based wildlife. A broad range of game can be found including elephants, hippos, and rhinos as well as buffalo, antelope, giraffe, warthog, wildebeest, lion, leopard, and cheetah. The diversity of bird life in Selous includes over 350 recorded species.

Arusha National Park, although smaller than most in Tanzania, has a range of habitats that consist of the forest of Mount Meru, Ngurdoto Crater in the southeast section of the park, and Momela Lakes, a series of seven crater lakes. Black and white Colobus monkeys are easily spotted in the forested area, while the marshy floor of the crater is dotted with herds of buffalo, zebra, and warthog. Momela Lake is home to a large selection of resident and migrant water birds.

Mount Meru is one of the most beautiful volcanoes in Africa and the second highest mountain in Tanzania. The summit is reached by a narrow ridge, which provides stunning views of the volcanic cone lying several thousand feet below in the crater. The ascent is steep, but the route passes through parkland, forest, a giant heather zone, and moorland.

Ruaha National Park is the least accessible park in Tanzania and as a result the landscape remains relatively untouched. Birdwatchers can enjoy over 400 species of bird that are not found in northern Tanzania, and the river, spectacular gorges, and majestic trees are especially appealing to photographers. As Tanzania's second largest park, Ruaha has large herds of buffalo, elephant, and gazelle. The densities of elephants are some of the largest in Tanzania.

Katavi National Park is located in a remote location offering unspoiled wilderness. A predominant feature in Katavi is the enormous floodplain, split by the Katuma River and several seasonal lakes. The lakes support enormous groups of hippos, crocodiles, and over 400 species of birds. One of the spectacles in Katavi is the hippos at the end of the dry season when as many as 200 try to squeeze into a pool of water. The male rivalry heats up causing territorial fights. The dry season brings Katavi National Park to life, and herds of impala, reedbuck, lions, zebras, and giraffes can be seen at the remaining pools and streams. An estimated 4,000 elephants and several herds of buffaloes in the thousands also converge on the park when the flood waters retreat.

Gombe Stream National Park is primarily for those who want to get a little off the beaten track and see chimpanzees. Many species of primates and mammals live in the park. Over 200 bird species have been recorded in the tropical forest, including barbets, starlings, sunbirds, crowned eagle, kingfishers, and the palm-nut vulture. Hiking and swimming are other popular activities; a trail leads into the forest to a waterfall in the valley.

Lake Victoria is the largest freshwater lake in Africa and is bordered by Kenya, Tanzania, and Uganda. This lake is the source of the White Nile and provides an income for millions of residents along its shores. The Tanzanian section of Lake Victoria is one of the least visited regions in the country; however, the towns of Bukoba, Musoma, and Mwanza have a number of attractions. Near Mwanza and Musoma are many islands; some have become wildlife sanctuaries. Bird watching and fishing trips are popular excursions, and boat trips or hikes can be arranged around Lake Victoria.

Most of the forests in Tanzania are in the mountains. Those of greatest importance in terms of species diversity and cndcmism are in the so-called "Eastern Arc" mountains from the Pares, south to the Southern Highlands. The highest priority areas are the Usambaras, Ulugurus, and Uzungwas. In the Usambaras, where there are numerous isolated forest patches and a very high human population density, current efforts to reconcile human and conservation needs should be intensified. This will include extending the current program in the east Usambaras to the west. In the Ulugurus, protected areas should be created, and further encroachment, especially on the lower eastern slopes, should be prevented. In the Uzungwas, there is a national park recommended for the eastern side and another protected area further south, from Dabaga to Chita, should be considered. It is important that protection in the Uzungwas includes the lowland forests in the eastern foothills and areas of montane grassland. Protection is also insufficient for forests on the Pare, Kama, Nguru, Ukaguru, and Rubeho Mountains and for forests in the Uzungwas away from the proposed national parks. In the Southern Highlands, forest conservation measures are needed for Mount Rungwe and the Poroto, Kipengere, Njombe, and Livingstone Mountains, including areas of montane grassland. Interesting outliers of the main "Eastern Arc" system are to be found in the Mahenge and Matengo Highlands. Conservation needs in these areas should be assessed. In western Tanzania, the most important patches of montane forest are to be found in the Mahale Mountain National Park. Other interesting forest patches are in need of conservation on the Ufipa Plateau, in particular the Mbisi Forest and a few other sites. The remaining montane forests in Tanzania are on volcanic soil, and although they are of less importance for rare and endemic species, they perform essential roles as water catchments.

The montane grasslands of southern Tanzania represent a poorly protected and rapidly declining habitat. This habitat occurs in the Southern Highlands, Udzungwa Mountains, and Ufipa Plateau and lacks the protection necessary to ensure its survival. Of particular importance is the Kitulo Plateau in the Southern Highlands, with its remarkable flora.

2.10.3 Endangered Species

The flora of Tanzania is extremely diverse, with over 10,008 higher plants. For breeding birds, their number is about 229 species. There are more than 360 species of mammals, more than 335 species of reptiles, more than 116 amphibian species, and almost 331 species of fish [48]. The marine environment has more than 7,805 invertebrate species [49].

Tanzania's unique biogeography has also endowed it with high levels of endemism – species found only in the country, often within a small range. Eastern Arc Mountain forests are one area of high endemism, with about 100 vertebrates (10 mammals, 20 birds, 38 amphibians, 29 reptiles) found there and nowhere else. About 1,500 plant species, including some 68 tree species, are endemic to the Eastern Arc Mountains. The Uluguru Mountains alone have about 135 plant species that are confined to that single mountain block, while more than 100 endemic species are known to exist in west and east Usambara Mountains and Udzungwa Ranges. Among Tanzania's 20 species of primates, 4 are endemic, including the Zanzibar red colobus (*Procolobus kirkii*). Of the 290 species of reptiles, 75 are endemic; and two of 34 species of antelopes are endemic. The Rift Valley Lakes contain an amazing diversity of cichlid fish, many of which are endemic. Lake Nyassa has over 600 fish species, Lake Tanganyika has more than 200 endemic fish, and Lake Victoria has around 200 species. Lake Tanganyika has over 470 fish species, including about 300 cichlids and over 170 non-cichlids. Lake Tanganyika is exceptional not only for its high level of species richness (animals, plants, and protists estimated at over 1,400 species) but also for high levels of endemism exhibited among several taxa. High numbers of endemic species [50, 51] represent all fish, copepods, ostracods, shrimp, crabs, and mollusks. In Tanzania, there are about 762 endemics species [2] as shown in Table 1.

2.10.4 Threats to Biodiversity

1. The management of Tanzania's protected areas has not been sufficient to prevent large-scale poaching of mammals and encroachment in certain areas. Similarly, the management of wildlife in multi-use zones outside protected areas has not generally been successful.
2. The country's system of reserves is under serious threat, notably montane and lowland forests, montane grassland, the Itigi thicket, much of the area around Lake Rukwa and Fungu Kisimkase (Latham Island), and the whole coastal and marine zone (including mangroves and coral reefs), where reserves have been designated but not implemented.
3. The coral reefs are subjected to destruction by dynamiting and industrial fishing methods, and forest clearance is very severe in certain areas, especially the Usambaras, and in parts of the coastal zone.
4. Trading of live animal is one of the largest in Africa, especially in birds and tortoises, and yet no attempts have been made to determine the effects of such trade on wild populations.
5. Fish introductions can have a major deleterious effect on native fish populations, as has happened in Lake Victoria. Such fish populations are also threatened by overfishing and pollution.

2.11 Uganda

2.11.1 Important Environmental Issues

Uganda is a land-locked country that borders Lake Victoria, the second largest freshwater lake in the world. Most of the country is fertile and well watered, with many natural lakes and rivers. Generally, the climate is tropical with one to two thousand millimeter of rain falling annually in two rainy seasons, although roughly 7% of the country is classified as arid or semiarid.

Ugandans have inherited a very rich flora and fauna, but the country is rapidly losing its biodiversity. The annual percentage of loss is about 1% [52]. The main causes for such loss include land degradation, deforestation, water pollution, wetland degradation, and population pressure.

Seventy-one percent of Uganda’s land area is potentially arable. However, rapid rural population growth and lack of access to improved inputs, overgrazing, and conversion of forests for agriculture have caused land degradation. The resulting rapid deforestation in Uganda (600 km^2/year) is also threatened by harvesting of wood for fuel as a primary source of energy [53]. Resulting soil erosion now accounts for environmental degradation in Uganda [54]. Those worst affected (85–90%) include the highland areas in the southwest, Kabale and Kisoro [55].

Threats to biodiversity and habitat degradation are directly attributed to natural factors including relief and climate as well as deforestation and unsustainable farming practices such as the cultivation of fragile lands [56].

Freshwater accounts for over 15% of Uganda’s surface area [57]. However, increased demand and use of pesticides, fungicides, herbicides, and fertilizers is affecting the water quality in Uganda. Agricultural practices account for 50% of nitrogen and 56% of phosphorus levels in Lake Victoria Basin. Additionally, the exploitation of petroleum threatens the overall ecosystems of Lake Albert and Edward Basins. The northern end of Lake George and its associated wetlands receive localized metal pollution from a former copper tailings and mine left after metal extraction. There is a high concentration of zinc, copper, cobalt, and nickel in the lake [9].

In 1964, the wetlands are made up 32,000 km^2 of Uganda, which reduced to 26,308 km^2 or 11% of total land area in 2005 [9].

2.11.2 Critical Sites

Uganda has four national parks. In the southwest is the Queen Elizabeth (formerly Rwenzori) National Park (also a biosphere reserve), which consists of grassland, savanna woodlands, swamps, lakeshore, and part of the Maramagambo Forest. Many large mammal populations were lost from this area through poaching.

The Queen Elizabeth Park is part of a much larger complex of contiguous protected areas, the others being the Kigezi, Kyambura, and Kibale Forest Corridor Game Reserves, the Kazinga Channel Sanctuary, and the Kasyoha–Kitomi, Maramagambo–Kalinzu, and Kibale Forest Reserves, as well as the large Virunga National Park in DRC.

The Lake Mburo National Park is also in the southwest and has some important, though depleted, wildlife populations. It is principally an area of wooded savanna, swamps, and lakes.

The Murchison (formerly Kabalega) Falls National Park consists of grassland, wooded savanna, and some small forest patches (e.g., Rabongo Forest) and is bisected by the Nile.

The Bugungu and Karuma Game Reserves are contiguous to it. The management of the area is now in need of improvement, following the years of political instability.

In the more arid northeast is the Kidepo Valley National Park, an area of bushed savanna. Wildlife populations have survived better here than elsewhere in Uganda, but there is a continuing problem with poaching which needs collaboration with the authorities in the adjacent Kidepo Game Reserve in Sudan. There is also a large army present there, which puts additional pressure on the park's resources.

Apart from these national parks and contiguous reserves, Uganda has a number of other reserves in the savanna zone, almost all of which have become seriously compromised. One of the most important is the Toro Game Reserve south of Lake Albert (Mobutu), where wildlife populations have been much reduced through poaching. The Katonga Game Reserve in the southwest is suffering from serious overgrazing by livestock. Poaching has been the problem in four small wooded savanna reserves in the West Nile area: Ajai's Game Reserve and Mount Kei, Otce, and Dufile Sanctuaries. The white rhinoceros is now extinct. In the semiarid northeastern province of Karamoja, there are three large and potentially important contiguous game reserves: Matheniko, Bokora Corridor, and Pian Upe. All have been subject to poaching and severe overgrazing by livestock, and wildlife populations are now sparse.

Uganda has biological resources in its forest ecosystems that are of international importance. The Bwindi (or Impenetrable) Forest Reserve is very important for its very wide altitudinal range of forest and a number of very rare species: there has been severe encroachment of this area, which was stopped in 1988, and the area is now proposed as a nature reserve. Of great richness is the Semliki (or Bwamba) Forest Reserve, which is contiguous with the huge Ituri Forest in DRC. The Rwenzori Forest Reserve including the Rwenzori Mountains is contiguous with the Virunga National Park in DRC. A substantial part of the Rwenzori Mountains is declared as a national park. In the extreme southwest of the country is the Gorilla Game Reserve, which is contiguous with the Volcanoes National Park in Rwanda. Agricultural encroachment of this area is a serious problem. Part of this area (the Mgahinga Forest Reserve) is scheduled to be declared a national park, with the surrounding game reserve being reestablished as a buffer zone and extending to lower altitude than at present. The Kibale Forest Reserve is an important area of intermediate, elevation forest that needs an increased level of protection. Several other forest reserves in western Uganda are generally managed for timber production as well as for conservation, and these require careful management to integrate human and conservation needs, with strict protection where necessary. The reserves in question are Budongo, Bugoma, Itwara, Kalinzu, Kasyoha–Kitomi, and Maramagambo–Kalinzu. Similar measures are doubtlessly required for the remaining forests around Lake Victoria (Sango Bay, Lake Shore, and Mabira) and also on Mount Elgon, where conifer plantations have been extended at the expense of natural forests in recent years and where a national park to complement the one in Kenya is desirable.

Uganda possesses some major wetland resources, as follows: 8,832 km^2 of swamps, 365 km^2 of swamp forests, and 20,392 km^2 of other wetlands. Important areas include the Lake Opeta floodplain, the surrounds of Lake Kyoga (especially the southern and western sides), and that of Lake Victoria (mainly on the north-western edge of the lake). A large area of swamps adjacent to Lake George is so far the only Ramsar site in East Africa. However, there are swamps, in particular papyrus swamps, in many other places, especially along the Nile Valley, and around the lakes in the Albertine Rift Valley. The unusual upland swamp forests of Kabale District are rapidly disappearing due to agricultural conversion. The conservation of all these areas needs addressing, probably in the context of well-designed integrated rural development projects.

Uganda’s lakes are of great interest and importance, especially Lakes Victoria, Kyoga, Bistna, Kwania, Albert, George, and Edward. None of these lakes is included in any reserve and inclusion of open water in protected areas is proposed.

2.11.3 Endangered Species

Uganda’s position in a zone between the ecological communities’ characteristic of the drier East African savannahs and the more moist West African rainforests, combined with wide altitude ranges, has led the country to be one of the most biologically diverse in Africa relative to its size. Uganda has a myriad of natural features including mountains, lakes, rivers, and the Great Rift Valley. It has 7 out of the 18 phytochoria (vegetation classifications) in Africa. The major natural ecosystems are forests, woodlands and savannahs, wetlands, open water, and mountain ecosystems.

In Uganda, the main terrestrial ecoregions are Victoria Basin forest savannah, East Sudanian savannah, and Northern Acacia Commiphora bush lands and thickets. Small patches of East African montane forests, East African montane moorlands, Albertine Rift montane forests, and Rwenzori–Virunga montane moorlands are also present in Uganda [58]. A very diverse set of vegetation types exists, ranging from the montane flora at 5,000 m.a.s.l. in the Rwenzori Mountains to the lowland forest (at 600 m.a.s.l).

There are 5,000 species of flowering plants and 406 gymnosperms and ferns recorded. Of these, 54 woody plants are considered to be under threat. These species are distributed in diverse ecosystem types, both natural and modified, such as forests, woodlands, wetlands and aquatic systems, agroecological zones, and urban environment. In Uganda, the total number of species is not known although a provisional list of 18,783 exists [59], which includes 380 mammals and over 600 fish species. Bird diversity is particularly rich; with 1,007 species, Uganda contains more than half of Africa’s bird species and about 10% of all the bird species in the world (EBAs) [60]. In Uganda, there are about 217 endemics species [2] as shown in Table 1.

2.11.4 Threats to Biodiversity

1. Uganda's protected areas have suffered from very extensive poaching and from encroachment.
2. Loss of tree cover to meet rapidly – increasing demands for timber, fuel wood, and charcoal.
3. Increasing pollution which, most noticeably, has affected the whole ecology of Lake Victoria and most other waters.
4. Uganda's wetlands also suffer from lack of protection.
5. Fish introductions can have a major deleterious effect on native fish populations, as has happened in Lake Victoria (most notoriously the Nile Perch into Lake Victoria).

3 Case Study Lake Nasser

3.1 Important Environmental Issues in Lake Nasser

Water is a key natural resource for future development and prosperity as well as stability. On the other hand, water is a scare resource; hence water saving is also gaining strategic significance and importance. Existing water shortages due to inadequate development, competing demands, and water quality degradation have been exacerbated. The number of people in countries where water is scare will continue to increase sevenfold only in the next 25 years. This situation is critical, especially in Egypt, and needs immediate actions. The challenges and opportunities in the water conservation sector in Egypt are big in both magnitude and direction. In 1960, the Government of Egypt took the decision of building Aswan High Dam (AHD) in order to trigger national development, maximize water saving, and protect the country from the flood hazard which Egypt had encountered many times in the past and caused thousands of fatalities and enormous economic loss. The AHD, which was inaugurated in 1970, is about 7 km distance upstream of the Old Aswan Dam. Lake Nasser/Nubia is one of the larger African man-made lakes. The dam formed a 450 km long reservoir, which extends southward 150 km beyond the Egyptian–Sudanese boundary about to the second cataract. The 300 km section in Egypt is known as Lake Nasser, and that part in the Sudan is called Lake Nubia.

Lake Nasser (22° 31′–23° 45′ N and 31°30′–33°15′ E) reached its operating level of 175 m asl in 1975, with a total amount of 121×109 m^3 of stored water. Of this, 31.6×109 m^3 is dead storage (water below the level of the sluices). The deepest zone is situated between 85 and 150 m asl. The central part is a river–lake: the current at the southern end of the Nubian region reaches 100–150 cm s^{-1}. This speed gradually drops to 10–20 cm s^{-1}, and in Lake Nasser, it is 0–3 cm s^{-1}. The mean depth of the central part gradually increases from 10 m at the southern end to 70 m in the north. Lake Nasser has a number of side extensions known as khors. Their mean length increases from south to north owing to the northwardly declining ancient riverbed. All khors have a "U" shape in cross section, with a flat sandy central belt. There are 100 important khors in Lakes Nasser and Nubia combined. Their total length when the lake is full is nearly 3,000 km and their total surface area is 4,900 km^2 (79% of total lake surface). In volume, they contain 86.4 km^3 water (55% of total lake volume). Some khors represent auxiliary, semi-isolated lakes. Khor Allaqi, Kalabsha, and Toshka are the largest. They have a sandy bottom, while others like Korosko and El-Sadake are steep, relatively narrow and have a rocky bottom.

Lake Nasser and Egypt are under threat by sedimentation and serious sand encroachment from the western and eastern deserts. Wind power is the most important factor in sand dune mobility because of the non-cohesiveness of the sand. Other factors that influence the mobility and stability of sand dunes are related to human activity such as the destruction of vegetation by grazing, trampling, and wood gathering [61].

The water quality status of the Lake Nasser is dependent mainly on potential impacts that could come from the Nile inflow upstream. The lake water is well oxygenated during winter and spring. Transparency is affected by the turbidity caused by silt and clay (allochthonous inorganic materials) of riverine origin. It is particularly strong in the flood season. The pH values are always on the alkaline side. The variation in EC and TDS follows, to a certain extent, the movement of water masses of the floodwater. The lowest conductivity within the surface water of the lake occurs during the flood period due to the low water conductivity of the flooded from Blue Nile, which contributes about 84% of the Nile flood. The sulfate is considered very low in the lake. Based on the total phosphorus, the lake is classified as eutrophic lake. The maximum record of average nitrate concentrations along the lake does not exceed 2.3 mg N/l. In spring and summer, the concentrations of silica within the lacustrine zone are almost the same; however in wintertime, they decrease. The values of BOD along Lake Nasser are low due to the high capacity of water in the main channel of the lake to assimilate the organic material in the presence of high levels of oxygen. The fecal coliform "FC" values range from 110 to 140 cfu/100 ml at the main channel, while during low water levels, their counts range from 400 to 800 cfu/100 ml at the main channel [62]. The concentration of all heavy metals is below the maximum permissible value set by the Environmental Protection Agency and Egyptian Chemical Standards [63].

Concerning the phytoplankton community structure in Lake Nasser, thirty-nine species belonging to three main groups in addition to some rare groups were recorded. Chlorophyceae was the most diversified group (19 species), followed by Cyanophyceae (10 species), Bacillariophyceae (7 species), and two rare groups which include Dinophyceae (2 species) and Euglenophyceae (1 species) [64]. The different groups were abundant in the reservoir zones with different ratios. Many studies showed that certain environmental factors, such as DO, water temperature, water velocity, turbidity, nitrate, total phosphorus, magnesium, total dissolved solids, and trophic state index, do affect the phytoplankton growth and the biodiversity in Lake Nasser [64, 65].

Concerning the zooplankton community structure in Lake Nasser, the zooplankton is rich and its assemblage consists of Copepoda, Cladocera, and Rotifera, besides Protozoa and meroplankton. The zooplankton population and it species biodiversity are mainly represented by typical limnoplankton forms including 79 species dominated by Copepoda (10 species), Cladocera (10 species), and Rotifera (48 species) [66]. The density of zooplankton is high toward the upstream. This is coincided with rich nitrate and orthophosphate. At the downstream, the fish predation increases due to high transparency, leading to decrease in the zooplankton density, while juvenile crustacean zooplankton and rotifers may actually increase under fish predation [67]. The density of zooplankton in Lake Nasser can be changed with the oscillation of the lake water level. The standing stock of zooplankton is higher at low water level in comparison with the highest level [68]. Furthermore, high fish production leads to high predation on zooplankton and thus decreases zooplankton density [69].

In Lake Nasser, the species composition of benthic organisms exhibited marked variations from one zone to another. This is attributed to the variations in the prevailing physicochemical conditions. The benthic fauna include 50 species dominated by insect (28 species), followed by mollusks (19 species), annelids (5 species), crustaceans (4 species), and one species of cnidarian and another species from bryozoan. The density of the benthic organisms decreases with decreasing the water's transparency and increasing the sedimentation especially in the lower part of the lake. Furthermore, the nature of the bottom sediments has a selective influence on quality and quantity of benthos, and it is considered the most significant factor determining their distribution. A positive correlation is found between most bottom fauna species abundance and the silt and clay fractions. In addition, there are positive correlation stands for the abundance of the bottom fauna and the total organic content. In addition, the temperature, electrical conductivity, dissolved oxygen, and pH are important factors in controlling the flourishing and existence of different species in Lake Nasser. The physicochemical features as well as the characteristics of the bottom sediments in Lake Nasser are in favor for producing high standing crop of benthos, which in turn provides the main food items for the various fish inhabitants of the lake [70].

Concerning the aquatic weed community structure in Lake Nasser, monitoring studies showed that there are no floating weeds in Lake Nasser. However, a total standing crop of the submerged aquatic weeds along the littoral zone of Lake Nasser is made up of nine species (*Potamogeton crispus*, *P. lucens, P. perfoliatus, P. trichoides, Myriophyllum spicatum, Najas marina* subsp. *armata, N. minor, Vallisneria spiralis*, and *Zannichellia palustris*) [71]. The submerged aquatic weeds are located at depths ranging between 1 and 6 m. However, at depths of 5 and 6 m, the existence of such weeds is very limited [72]. The distribution of the submerged aquatic weeds tends to be the highest near the northern and middle parts of the lake, gradually decreases toward the southern part, and almost disappears near the Sudanese border [71–73]. The standing crop for the submerged aquatic weeds at different depths (1–6 m) does not vary greatly with time. The correlation between the standing crop of the submerged aquatic weeds and some physicochemical parameters within the surface water is poor. The key environmental factors, which affect weeds, are water-level fluctuation, light penetration, bed slope, and hydrostatic pressure. Finally, the sediment texture with its organic content is less useful predictors of the community structure for the submerged aquatic weeds, and many authors consider the water-level fluctuation the most important factor that controls the distribution of shoreline and aquatic vegetation [72, 73].

Concerning the fish community structure in Lake Nasser, 36 species of fish are known from the lake, but it is likely that 57 are present, based on fishes known from the river in upper Egypt and in lower Sudan. The fish biodiversity of the lower Nile River is considerably less rich than that of the upper river. Numerically, the most abundant open-water species are the tiger fish (*Hydrocynus forskahlii*), three species of *Alestes* (*A. baremoze, A. dentex*, and *A. nurse*), the pelagic siluroid (*Eutropius niloticus*) and a small cyprinid (*Chelaethiops bibie*). From a weight standpoint of the lake, tiger fish appear to be much more abundant than *Alestes*. The reverse is true toward the upper end. *Alestes baremoze* and *A. dentex* comprised about 12 and 74% of the total catch by weight of all open-water fish from the lower and the upper ends, respectively [74]. During the winter circulation period, tiger fish *A. baremoze* and *A. dentex* are fairly well scattered vertically, down to 20–30 m. During the summer stagnation period, they probably are restricted almost entirely to the upper 10–15 m, in or above the metalimnion. Dense aggregations of any open-water species have not often been observed. The main plankton feeders in open water are three species of *Alestes*, *E. niloticus*, three species of *Labeo*, and two small cyprinids, *C. bibie* and *Barilius niloticus*. The tiger fish is the main predator, but in the spring and early summer, its spawning period the Nile perch also is important. The inshore fish fauna is more complex than the open-water community, but only a few species dominate it also. Numerically, the principal species are *Tilapia nilotica*, two small cyprinids (*C. bibie* and *B. niloticus*), tiger fish, and Nile perch. The smallest species of siluroids are not concentrated anywhere, but discrete pockets of some of those that attain large size, particularly *Clarias lazera*, are seen during the summer stagnation period. Juvenile *T. nilotica* school densely along the shore in shallow water as do adults at the surface over deeper water, except in mid-winter [75, 76].

Concerning the amphibians and reptiles, 2,486 herpetological specimens were collected during 1962 and 1965, representing 51 species and 13 families. Among the herpetological specimens is a series of 1,232 *Chalcides ocellatus* and a recently described species of spitting cobra (*Naja nubiae*). Because most of the collection sites are now under Lake Nasser, most specimens represent extirpated populations [77]. Some specimens are of taxa now considered endangered species in Egypt especially crocodiles, Nile turtle, Nile monitor, and cobras. The activities of human settlements, fishermen, agricultures, and traffic tourism as well as water pollution are having a severe influence on the composition and species biodiversity of both amphibians and reptiles. It is predicted that the amphibian fauna may flourish with flourishing of the agricultural practices along the shoreline of the lake.

Lake Nasser also provides critical habitats for many species of mammals. Mammals of the area, particularly those that are known to be threatened, require further, more detailed studies. These may include the ecology and biology of these species covering basic aspects such as population size and dynamics, home range, habitat requirements, competition with feral domestic mammals, and impact of human activities. Wild carnivores have suffered a great deal of decline in recent years because of secondary poisoning with pesticides widely used to control Nile rat and other rodent pests. Gazelle species are showing decline in population size due to habitat fragmentation, hunting, and grazing overlap with domestic Bovidae family.

Since the construction and filling of the Lake Nasser, the lake began to be suitable habitat for water birds, especially that the area is an important route for migratory birds coming from Europe in autumn, either to stay or as a station to go further south in Africa. There are impressive varieties of birds at Lake Nasser. The lake has become increasingly important as a wintering area for migratory Palearctic water birds [78]. Those kinds of birds could be ecologically a disaster because of mismanagement of shoreline agriculture and tourism activities.

3.2 Endangered Species in Lake Nasser

3.2.1 Fish

Protopterus aethiopicus, Polypterus bichir, Mormyrops anguilloides, Petrocephalus bane, Pollimyrus isidori, Gnathonemus cyprinoides, M. caschive, Hyperopisus bebe, Gymnarchus niloticus, Labo horie, L. coubei, L. victorianu, Garra dembeensis, Barbus neglectus, Barbus werneri, Barbus anema, Leptocypris nioticus, Raiamas loati, Chelaethiops bibie, Hydrocynus vittatus, Hydrocynus brevis, Alestes dentex, Alestes baremoze, Distichodus niloticus, Citharinus citharus, Citharinus latus, Bagrus degeni, Chrysichthys rueppelli, Clarotes laticeps, Auchenoglanis biscutatus, Auchenoglanis occidentalis, Schilbe (Eutropius) niloticus, S. uranoscopus, Clarias anguillaris, Heterebranchus bidorsalis, Heterobranchus longifilis, Malapterurus electricus, Synodontis serratus, Synodontis clarias, Mochocus niloticus, Chiloglanis niloticus and *Tetraodon lineatus.*

The extinct fishes: *Mormyrus hasselquist, M. niloticus, Heterotis niloticus, Brycinus macrolepidotus, Micralestes acutidens, Ichthyoborus besse, Distichodus rostratus, Distichodus engycephalus, Nannocharax niloticus, Brachysynodontis batensoda, Hemisynodontis membranaceus* and *Aplocheilichthys schoelleri* [2].

3.2.2 Amphibians and Reptiles

Bufo kassasii, *Bufo regularis*, *Bufo viridis*, *Hemidactylus turcicus*, *Ptyodactylus hasselquistii*, *Ptyodactylus siphonorhina*, *Stenodactylus sthenodactylus*, *Tarentola annularis, Tropiocolotes steudneri*, *Pseudotrapelus sinaitus*, *Acanthodactylus boskianus*, *Acanthodactylus scutellatus*, *Mesalina guttulata*, *Mesalina rubropunctata*, *Varanus griseus*, *Varanus niloticus*, *Chalcides* cf. *humilis*, *Psammophis aegyptius*, *Psammophis sibilans*, *Naja nubiae*, *Naja haje*, *Cerastes cerastes*, *Crocodylus niloticus* and *Trionyx triunguis* [2].

3.2.3 Mammals

Vulpes vulpes, Hyaena hyaena, Gazella leptoceros, Gazella dorcas, Nubian ibex and *Felis margarita* [2].

3.2.4 Birds

Marmaronetta angustirostris, *Gypaetus barbatus*, *Gyps fulvus*, *Terathopius ecaudatus*, *Aquila chrysaetos*, *Chlamydotis undulata*, *Numenius tenuirostris*, *Rynchops flavirostris*, *Oenanthe moesta*, *Vanellus gregarious*, *Neophron percnopterus*, *Buteo rufinus*, *Aquila clanga*, *Aquila heliaca*, *Falco naumanni*, *Falco biarmicus*, *Falco pelegrinoides*, *Alectoris chukar*, *Crex crex* and *Turdoides squamiceps* [2].

3.3 Threats to Biodiversity in Lake Nasser

The lake provides good habitat for establishing the community structures for many species that play an important role in providing habitat complexity, food to aquatic animals, nutrient recycling, and nesting for both fish and birds.

Since the early filling of Lake Nasser, extensive and comprehensive studies have been carried out on the various aspects of the lake species biodiversity and social and economic functions, by research workers, experts, and international bodies. These studies concluded that the main sources of biodiversity degradation in Lake Nasser are development of land, expansion of agricultural land, and disappearance of habitat from excessive grazing or application of agrochemicals, as well as habitats being polluted, and hunting, fishing, and tourism activities disturbing the natural habitat especially within the shoreline zone. The summary of all such activities and their effects on biodiversity degradation are shown in Table 2.

Table 2 Causes of biodiversity degradation in Lake Nasser

Indicators	Factors	Threatened organisms
Water-level fluctuation	Loss or degradation of habitat	Dramatic decline in birds, aquatic weeds, shrubs, mussels, snails, reptiles, fish, and mammals
Thermal stratification	Biodiversity loss Water quality will change	The community structure for certain aquatic organisms will be changed, such as bacteria, fungi, planktons, and fish
Sedimentation	Loss or degradation of the habitat	It affects the benthic organisms, fish, and submerged aquatic weeds
Sand dune	Loss or degradation of the habitat	It affects reptiles, turtles, fish, aquatic weeds, and different benthic organisms, as well as mammals and birds
Over grazing (livestock)	Loss or degradation of the habitat	It affects aquatic weeds, different benthic organisms, mammals, and birds
Pollution of habitat (land pollution)	Dramatic decline of the density and species biodiversity	It affect birds, mammals, and reptiles
Pollution of habitat (water pollution)	Dramatic decline of the density and species biodiversity	It affects all the community structures of aquatic organisms as well as birds and reptiles
Hunting for recreational demands	Dramatic decline of the density and species biodiversity	It affects mammals, birds, and reptiles
Hunting and overfishing for food	Dramatic decline of the density and species biodiversity	It affects mammals, birds, fish, and turtles
Human-caused disturbance: navigations, tourism, or recreation	Loss or degradation of the habitat	It affects fish, mammals, birds, and reptiles
Climate changes	–Change amounts of rain that falls on the Nile Basin with the presence of periods of drought –Increase temp. –Increase wind unit	The climate changes will affect the community structures and the richness of most of the aquatic organisms, mammals, birds, and reptiles because of loss or degradation of the habitat and increase of both air and water temperature

It is clear from Table 2 that both the developmental activities and human behaviors may destroy the ecosystem and species biodiversity in Lake Nasser if the laws and regulations regarding environmental preservation are not activated.

4 Conclusions

Nile Basin countries face several problems. Some of these problems are but not limited to inefficient water use, water pollution, population pressure and land degradation, deforestation and soil loss, overhunting and overfishing, and sedimentation problems.

In addition, the study concluded that the main sources of biodiversity degradation in Lake Nasser are development of land, expansion of agricultural land, and disappearance of habitat from excessive grazing or application of agrochemicals, as well as habitats being polluted, and hunting, fishing, and tourism activities disturbing the natural habitat especially within the shoreline zone.

References

1. Kimunya M (2010) Biodiversity strategy and action plan for sustainable management of the Mara River Basin. Lake Victoria Basin Commission and WWF-ESARPO
2. IUCN (2009) IUCN Red List of Threatened Species. Accessed at: www.redlist.org (Last modified on Wednesday 11 June 2014)
3. Molden D, Awulachew SB, Conniff K, Rebelo L-M, Mohamed Y, Peden D, Kinyangi J, van Breugel P, Mukherji A, Cascão A, Notenbaert A, Demise SS, Meguid MA, el Naggar G (2009) CPWF Project Report, Nile Basin Focal Project Project Number 59
4. National Water Research Center (2007) Nile River Basin Baseline (Revised report)
5. Burundi population density. http://www.countrymeters.info/en/Burund
6. Atlas country profile. https://na.unep.net/atlas/profiles/english/Burundi.pdf
7. FAO (2005) AQUASTAT country profile Burundi. FAO, Rome. http://www.fao.org/ag/agl/aglw/AQUASTAT/countries/index.stm
8. FAO (2016) Forest area statistics Burundi. http://www.fao.org/forestry/country/32185/en/bdi/
9. Strategic Foresight Group (2013) Blue Peace for the Nile. C-306 Montana, Lokhandwala Complex, Andheri West, Mumbai 400 053, India
10. United Nations Environment Programme (UNEP) (1999) Global Environment Outlook 2000. http://www.unep.org/geo2000/index.htm. Accessed 5 Oct 2005
11. FAO (2016) Forest area statistics DRC. http://www.fao.org/forestry/country/32185/en/cod/
12. Forests for People and the Environment: CIFOR Annual Report (2004) By Center for International Forestry Research, Cifor
13. National geographic Adapted from http://www.nationalgeographic.com/wildworld/profiles/terrestrial/at/at0718.html and http://www.feow.org/ecoregion_details.php?eco=546 with additional material
14. Seyler JR, Thomas D, Mwanza N, Mpoyi A (2010) Democratic republic of Congo: biodiversity and tropical forestry assessment (118/119), Final report. United States Agency for International Development
15. FAO (2005) AQUASTAT country profile Egypt. FAO, Rome, http://www.fao.org/ag/agl/aglw/aquastat/countries/index.stm
16. UNEP (2006) Africa: Atlas of Our Changing Environment
17. Egypt population Density. http://www.countrymeters.info/en/Egypt/
18. Environment, Department Of the Environment National (1997) Report
19. FAO (2005) AFRICOVER, Eritrea - spatially aggregated multipurpose land cover database. FAO, Rome, Italy, http://www.africover.org, 13/12/2004

20. FAO (2005) AQUASTAT country profile Eritrea. FAO, Rome, http://www.fao.org/ag/agl/aglw/aquastat/countries/index.stm, 08/11/2005
21. FAO (2016) Forest area statistics Eritrea. http://www.fao.org/forestry/country/32185/en/eri/
22. FAO (1997) Irrigation potential in Africa: a basin approach. FAO Land and Water Bulletin 4, FAO Land and Water Development Division. http://www.fao.org/documents/show_cdr.asp?url_file=/docrep/W4347E/W4347E00.htm. Accessed 9 Nov 2005
23. The State of Eritrea, Ministry of Land, Water and Environment Department of Environment. The 5th National Report On The Implementation Of The UNCBD (2014) Convention on Biological Diversity
24. The National Environmental Management Plan of Eritrea (NEMP-E) (1996) Society for International Development. Berlin Chapter. By Brigitte Fahrenhorst, Heinrich-Böll-Stiftung, SID, Indiana University, Digitized. 2008
25. National Action Programme for (2002) To combat desertification and mitigate the effect of drought. Ministry of Agriculture, Asmara, Eriterea. www.uncedint/actionprogrammes/africa/national/NAP/2002-eng.pdf (Dec 2005)
26. FAO (2005) AQUASTAT country profile Ethiopia. FAO, Rome. http://www.fao.org/ag/agl/aglw/AQUASTAT/countries/index.stm, 08/11/2005
27. USAID/Ethiopia (2008) Ethiopia Biodiversity and Tropical Forests 118/119 Assessment. EPIQ IQC: EPP-I-00-03-00014-00, Task Order 02
28. Birdlife Data Zone. http://www.birdlife.org/datazone/sites/indexhtml?action=SitHTMDetails.asp&sid=6282&m
29. Information about the tentative list are provided at http://whc.unesco.org/en/tentativelist/
30. IRIN (2006) Pastoralists face bleak future if help delays – Oxfam. http://www.irinnews.org/report/58430/kenya-pastoralists-face-bleak-future-if-help-delays-oxfam
31. UN-REDD (2012) The Role and Contribution of Montane Forests and Related Ecosystem Services to the Kenyan Economy. Published by the United Nations Environment Programme (UNEP)
32. UNESCO (1999) Lake Nakuru National Park. Kenya Wildlife Service P.O. Box 40241, Nairobi, Kenya. http://whc.unesco.org/en/tentativelists/1344/
33. National Environment Secretariat (2002) National Action Programme A Framework for Combating Desertification in Kenya in the Context of the United Nations Convention to Combat Desertification
34. USAID/Kenya Strategic Plan (2000) Environmental Threats and Opportunities Assessment
35. FAO (2005) AQUASTAT country profile Rwanda. FAO, Rome. http://www.fao.org/ag/agl/aglw/AQUASTAT/countries/index.stm
36. Rwanda population density (2016) http://countrymeters.info/en/Rwanda
37. Rwanda Environment Management Authority (2009) Rwanda's Fourth National Report to the Convention on Biological Diversity
38. Expert Africa (2014) Nyungwe National Park. https://www.expertafrica.com/rwanda/nyungwe-forest-national-park
39. National Strategy and Action Plan for the conservation of biodiversity in Rwanda (2003)
40. Rwanda Environmental Threats and Opportunities Assessment (ETOA) (2008) United States Agency for International Development. It was prepared by Chemonics International Inc
41. GCF. Country Profile South Sudan Giraffe Conservation Status Report. www.giraffeconservation.org/download_project.php?id
42. USAID Sudan (2007) Southern Sudan Environmental Threats and Opportunities Assessment Biodiversity and Tropical Forest Assessment. United States Agency for International Development. It was prepared by International Resources Group (IRG)
43. FAO (2005) AQUASTAT country profile Sudan. FAO, Rome. http://www.fao.org/ag/agl/aglw/AQUASTAT/countries/index.stm
44. Sudan Population Density (2016) http://countrymeters.info/en/Sudan

45. USAID/Sudan Integrated Strategic Plan (ISP) (2012) Sudan Environmental Threats and Opportunities Assessment with Special Focus on Biological Diversity and Tropical Forest. Contracted under DFD-I-00-05-00251-00, Task Order # 2
46. NBS (2014) Statistical abstract of the National Bureau. Ministry of Finance, Dares Salam
47. Winrock International (2006) Summary of case study-Tanzania. http://www.profor.info/profor/Documents/pdf/livelihoods/TanzaniaCaseStudy.pdf
48. EarthTrends (2003) Biodiversity and Protected Areas- Tanzania. http://www.vub.ac.be/klimostoolkit/sites/default/files/documents/tanzania_bd.pdf
49. Stuart SN, Adams RJ, Jenkins DM (1990) Biodiversity in sub-Saharan Africa and its islands: Conservation, management, and sustainable use. A contribution to the biodiversity conservation strategy programme (Occasional papers of the International Union for the Conservation of Nature Species Survival Commission, No. 6). World Conservation Union, Gland
50. Byers B, Aloyce Z, Munishi P, Rhoades, CC (2012) Tanzania Environmental Threats and Opportunities Assessment. Prepared for USAID-Tanzania
51. USAID-Tanzania (2012) Tanzania environmental threats and opportunities assessment. Prepared by ETOA Team: Bruce Byers (Team Leader), Zakiya Aloyce, Pantaleo Munishi, and Charles Rhoade
52. Arinaitwe H, Pomeroy DE, Tushabe H (2000) The State of Uganda's biodiversity 2000. MUIENR, Kampala
53. Naughton-Trevesa L, Kammenc DM, Chapmand C (2007) Burning biodiversity: Woody biomass use by commercial and subsistence groups in western Uganda's forests. Biol Conserv 134(2007):232–241
54. NEAP (1995) The national environmental action plan for Uganda. Ministry of Natural Resources, Kampala
55. NEMA (2001) Uganda State of the Environment Report 2000, Version 2. National Environment Management Authority, Ministry of Natural Resources, Kampala
56. Serunkuuma D, Pender J, Nkonya E (2001) Land management in Uganda: characterization of problems and hypotheses about causes and strategies for improvement. Project on Policies for Improved Land Management in Uganda. Report
57. FAO (2005) AQUASTAT country profile Uganda. FAO, Rome, http://www.fao.org/ag/agl/aglw/AQUASTAT/countries/index.stm
58. URL: http://worldwildlife.org/science/wildfinder/. Accessed 07/09/2012
59. National Environment Management Authority (2006) Third National Biodiversity Report. National Environment Management Authority (NEMA), Kampala, Uganda
60. URL: http://www.birdlife.org/datazone/country/uganda. Accessed 05/09/2012
61. Khairy W (2004) Terms of reference for Egypt, Eastern Nile Subsidiary action program (ENSAP-IDEN), National Project Coordinator - Integrated Watershed Management Project, Nile Water Sector Team, MWRI
62. Nile Research Institute (2011) "Evaluation of Water Quality Monitoring Network for Nile River", unpublished report, issued June 2011
63. EEAA (2010) Egypt State of Environment
64. Gharib SM, Abdel-Halim AM (2006) Spatial variation of phytoplankton and some physicochemical variables during the highest flood season in Lake Nasser (Egypt). Egypt J Aquat Res 32(1):246–263
65. Talaat AS (2011) Variation of water quality and phytoplankton along different zones of Aswan High Dam Reservoir. Egypt J Aquat Biol Fish 15(2):87–104 (2011) ISSN 1110–1131
66. Abu-Gideiri YB, Ali MT (1975) A preliminary biological survey of Lake Nubia. Hydrobiologia 46:535–541
67. El Shabrawy GM, Dumont HJ (2003) Spatial and seasonal variation of the zooplankton in the coastal zone and main khors of Lake Nasser (Egypt). Hydrobiologia 491:119–132
68. El Shabrawy GM (2000) Seasonal and spatial variation in zooplankton structure in Lake Nasser. I-Pelagic area of the main channel. Egypt J Aquat Biol Fish 4(3):75–101

69. Agaypi MZ (2000) A note on the relationship between catch and water level. In Craig JF (ed) Sustainable fish production in Lake Nasser: ecological basis and management policy. ICLARM Conference Proceedings 61:85–86
70. Iskaros IA, El Dardir M (2010) Factors affecting the distribution and abundance of bottom fauna in Lake Nasser, Egypt. Nat Sci 8(7):95–108
71. Abdel-Meguid M (2006) The submerged aquatic weeds and their role in the metabolism of the littoral zone in Lake Nasser. Eng Res J 104:C49–C60
72. Abdel-Meguid M, Bakry MF (2003) The effect of certain Biotic and abiotic factors on the growth and distribution of the submerged weeds along the littoral zone of Lake Nasser. J Egypt Acad Soc Environ Dev 4(3):179–199
73. Abdel-Meguid M, Bakery MFM (2012) The influences of selected environmental factors on the establishment of the submerged aquatic weeds in Lake Nasser. Nile Basin Water Sci Eng J 5(1):37–48
74. Dewitt JM (1972) Lake Nasser, its fish, and its fisheries. Cal-Neva wildlife
75. Khalifa US, Agaypi MZ, Adam HA (2000) The population dynamics of *Oreochromis niloticus* and *Sarotherodon galilaeus* Art. In: Craig JF (ed) Sustainable fish production in Lake Nasser: ecological basis and management policy. ICLARM Conference Proceedings 61:184 pp
76. Latif AFA (1974) Fisheries of Lake Nasser and Lake Nubia. In: Entz B, Latif AFA (eds) Report on a trip to Lake Nasser and Lake Nubia, Aswan Reg. Plan. Lake Nasser Development Centre, Egypt, pp 46–137
77. Gregory J, Watkins-Colwell, Dornburg A, Hawlena D, Moore JA (2010) The amphibians and reptiles of the 1962–1965 Yale University prehistoric expedition to Nubia. Bull Peabody Mus Nat Hist 51(2):179–197
78. Ibrahim WA (2009) Birds. In: Wetlands and biodiversity baseline report for Egypt. Nile Transboundary Environmental Action Project May, 2009

Impact of Water Quality on Ecosystems of the Nile River

Mostafa Mohamed El-Sheekh

Abstract The Nile River is the most important freshwater resource for life and the main source for drinking and irrigation along the basin from its origin until its estuary in Northern Egypt. In order to secure water from African countries located on the Nile River, the sustainable use of water and maintenance of its good quality is a fundamental objective. The pollution status of the water of the Nile River is an important indicator of water quality. In this chapter, the different pollutants of the Nile River are discussed in relation to the biotic and abiotic factors that affect water quality and the aquatic ecosystem. Human activities and increase in population have had a large impact on water quality, for example, through discharge of treated and untreated sewage, manufacturing, mining, construction, agricultural wastes, and transportation and oil spills. Other toxic substances which can be secreted by certain types of algae and cyanobacteria can affect the water quality and are expressed by deterioration in color and taste of water. The Nile River in Egypt is considered the principal artery of life in Egypt, and its water quality is characterized by high nutrient concentrations such as nitrates, nitrite, ammonia, nitrogen, phosphates, sulfates, and silicates. Heavy metals from industrial wastewater and other sources may affect the distribution and growth of some undesired microorganisms. Heavy metals also affect the aquatic organisms especially fish which affects the human health. The Nile River is subjected to different organic pollution levels from human activities. These organic pollutants may derive from industrial, agricultural, or domestic wastewaters in the Delta region where the industrial and agricultural activity increase due to the increase of population. The industrial wastewater contains organic matter, suspended materials, heavy metals, as well as oils and other pollutants which include chemicals, fertilizers, insecticides, sugar, aluminum, steel, soap and paper, and oil spills from navigation and other activities. The water

M.M. El-Sheekh (✉)
Department of Botany, Faculty of Science, Tanta University, Tanta 31527, Egypt
e-mail: mostafaelsheikh@science.tanta.edu.eg; mostafaelsheekh@yahoo.com

A.M. Negm (ed.), *The Nile River*,
Hdb Env Chem (2017) 56: 357–386, DOI 10.1007/698_2016_97,

quality assessment methods as well as water characteristics are discussed. The effect of fish cages and fish farming on the water quality and freshwater aquatic ecosystem of the Nile River is also discussed in relation to pollutants secreted by the fish and the feed. Monitoring the Nile River water regularly and continuously can help to achieve an understanding of how this system functions which in turn can help to identify the sources and fates of contaminants to inform how to keep the water quality within safe limits for different uses.

Keywords Ecosystem, Nile River, Phytoplankton biodiversity, Pollution, Water quality, Water quality assessment

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1 Introduction

The Nile River name originates from the Greek word “Nelios,” meaning river valley. The Nile River is the longest river in the world, running through ten African countries; it is a source of life to millions of people, flowing 6.825 km from south to north. The Nile starts in Burundi and flows into the Mediterranean Sea in North Egypt [1]. As development which expands in agriculture, industry, and urbanization has progressed, the side effects associated with these practices increased, namely, in the form of various pollutants. These pollutants are agrochemicals, heavy metals, or human waste products. Moreover, tourist activities on the riverbanks from hotels, shops, and numerous factories producing organic and industrial wastes pollute the Nile River water. Specialists estimate that every year, almost 275 million tons of organic and industrial waste are thrown, from hospitals and hotels directly into the river and sewage systems in the Egyptian Nile. Although the Egyptian Ministry of Environment as well as other African countries announced a multimillion dollar plan to raise awareness about the importance of keeping the Nile clean, the results so far are not visible. The attitude of washing clothes and utensils, plastics, metal products, and dead animals and birds in the river is another aspect that is destroying this legendary river. In addition, pollution caused by inadequate drainage systems in rural villages, and irrigation wastewater filled with fertilizers and pesticides, flows into the river channel. The water of the Nile River originates from rainfall generated in the Blue Nile and the White Nile coming from two major areas: the Ethiopian Plateau and the mountainous hinterland of the Great Lakes in Uganda, respectively. In general, different analytical methods were constructed to monitor the water quality status in freshwater ecosystems. It is important that environmental lawyers and policy makers work to define regulation to ensure that water is maintained at appropriate quality for its identified use. This chapter reviews the effects of pollution on the water quality of the Nile River, the sources of different pollutants, and the impacts on the aquatic ecosystem.

2 Water Quality of the Nile River

The Nile River flows through Egypt for about 950 km starting from downstream to the High Aswan Dam in Upper Egypt to upstream to the Delta Barrage, where it divides into Rosetta and Damietta branches. Each branch runs separately to the Mediterranean Sea, forming the Delta region between the two branches. The Rosetta branch represents the main freshwater stream that extends northward for about 239 km on the western boundary of the Nile Delta from Egypt's Delta Barrage [2]. The term water quality is defined as the suitability of water for various uses or processes [3]. The water quality also is expressed in terms of the state and concentration of the organic and inorganic nutrients present in the water, together with certain physical and chemical characteristics of the water [4]. The water quality of the Nile River is influenced by the agricultural, industrial, and touristic activity along the banks of the River in many countries upstream to downstream. Most of the pollution input to the water comes from drainage discharge. Ezzat et al. [5] studied the water quality of the Rosetta branch of the Nile River in Egypt along 120 km and five drainage stations. They recorded high concentrations of NH_3, total dissolved solids (TDS), electric conductivity (EC), biological oxygen demand (BOD), total alkalinity, turbidity, and recognizable depletion in dissolved oxygen (DO). Many researchers investigated the water quality of the Nile River, and they used the water quality index to summarize large amounts of water quality data into simple terms (e.g., good, average, or poor) for reporting to management. It is useful information about the overall quality for the different water resources for different water uses [6]. Agricultural and sewage wastes are the key factors in the environmental problem for the Nile. Self-purification and dilution concepts did contribute to the gradual improvement in water of the Nile River quality. The study of Ezzat et al. [5] recommended treating wastewater prior to discharge or to reuse it, as well as regular and constant monitoring for the Nile River to mitigate health problems, outbreaks or any aquatic ecosystem disorders. The applied water quality index (Canadian Water Quality Index) has been developed by the Water Resources Management Division for application in Newfoundland and Labrador. Water quality variables (e.g., DO, BOD, NO_3) are compared to water quality guidelines or site-specific objectives. The results of those comparisons are combined to provide a water quality ranking (good, average, poor) for individual water bodies [6, 7]. Also, Radwan [6] stated that the advantage of an index includes the ability to represent measurements of a variety of variables in a single number, the ability to combine various measurements in a variety of different units in a single metric, and the facilitation of communication of the results. The index is based on three attributes of water quality that relate to water quality.

2.1 Water Quality Parameters

Radwan [6] studied the different water quality parameters for the Nile River and the drains, namely, dissolved oxygen (DO), nitrate (NO_3), biochemical oxygen demand (BOD), and chemical oxygen demand (COD). She calculated the water quality index for the Nile River, and the results revealed that DO, NO_3, and BOD vary from good to excellent for the Nile River and from fair to good for the drains. The results also revealed that the water quality index (WQI) supported the analytical data, and the correlation coefficient matrix between water quality pairs recorded several positive and negative significant relationships.

2.1.1 Dissolved Oxygen

Oxygen is very important for life in the aquatic system, and any disturbance in the level of oxygen can affect the food web and hence affect the water quality of river. During photosynthesis, oxygen enters the water by aquatic organisms and by the transfer of oxygen across the air-water interface. The amount of dissolved oxygen in the water depends on the water temperature, salinity, and pressure. Cold water contains more oxygen than warm water; also freshwater contains more oxygen than saltwater or brackish water. The amount of oxygen dissolved in water decreases as altitude increases due to the decrease in relative pressure [8].

In rivers and all aquatic systems, dissolved oxygen is necessary for good water quality. Oxygen is a necessary element to all forms of aerobic aquatic life-forms; stress occurs when dissolved oxygen levels drop below 5.0 mg/l. Fish can be killed when oxygen levels remain below 1–2 mg/l for a few hours. Dissolved oxygen levels decrease may be as a result of presence of too many bacteria and an excess amount of biological oxygen demand (BOD) (untreated or partially treated sewage, organic discharges, and anoxic discharges) which consume dissolved oxygen.

Excessive algae growth caused by phosphorus and nitrogen also play a role in the decrease of dissolved oxygen (DO). The algae death and decomposition consume dissolved oxygen, and this results in low amounts of dissolved oxygen available for aquatic life, especially fish.

2.1.2 Biological Oxygen Demand (BOD)

Biological oxygen demand (BOD) is the amount of oxygen consumed by bacteria during the decomposition of organic materials or the oxygen required for the oxidation of various chemicals in the water, such as sulfides, ferrous iron, and ammonia. BOD is a good indicator for water quality. Good quality and unpolluted water must contain BOD of 5 mg/L or less. On the other hand, BOD of the polluted sewage has values ranging from 150 to 300 mg/L [9].

2.1.3 Chemical Oxygen Demand (COD)

The chemical oxygen demand (COD) is a test commonly used to indirectly measure the amount of organic compounds in water. COD is commonly used to determine the amount of organic pollutants found in lakes and rivers or wastewater. COD is a useful measure of water quality. It is expressed in milligrams per liter (mg/L), which indicates the mass of oxygen consumed per liter of solution [10].

2.1.4 Fecal Coliform

Fecal coliform can be used as indicator for water pollution and hence for water quality measure [11]. Total coliform bacteria are a group of relatively harmless microorganisms such as fecal coliform bacteria, enterococci bacteria, and *Escherichia coli* bacteria that live in large numbers in the intestines of humans and animals. The occurrence of fecal coliform bacteria in aquatic systems such as the Nile River and its branches indicates the water is contaminated with waste from human activity. The wastes from humans and animals also may be carried out to the water bodies, and it may contain pathogenic bacteria or viruses. Fecal coliform, enterococci, and *E. coli* bacteria are used as indicator organisms, as a likelihood of finding pathogenic organisms in a stream.

2.1.5 pH

The water quality of the Nile River affects with the changes in the pH of the water. pH is an important limiting chemical factor for aquatic life which may affect the aquatic organisms' biochemical reactions. The severe changes of pH of the water may cause a harmful or even lethal effect on aquatic organisms and consequently affect the animal and human health. Generally, water streams have pH ranging, between 6 and 9, and any changes in this range in pH can affect life-forms in aquatic systems. If the pH increases above this range, smaller amounts of ammonia are needed to reach a level that is toxic to fish, while when pH decreases, acidity of the water increases affecting the fish [9].

2.1.6 Temperature

Water temperature is an important factor which directly or indirectly affects the water quality and aquatic life. Water temperature changes in the aquatic system may also influence different factors, such as the quantity and velocity of stream flow, stream vegetation, and, in a lesser extent, the sun. Temperature has an influence on the concentration of dissolved oxygen in a water body. Oxygen is more easily dissolved in cold water than warm water [9]. Also, temperature affects the speed of chemical reactions and the metabolism of aquatic organisms [5]. Water temperature of the Nile depends on the area and country climate. For example, in Egypt, temperatures of Nile water show low values during the winter season and increase toward the summer season. Temperatures ranged from a low value of 15°C (during winter) to a high value of 31°C (during summer) [12].

2.1.7 Turbidity

Turbidity is a measure of fine suspended matter in the water column or the cloudiness of water such as clay, silt, nonliving organic particulates, plankton, and other microscopic plants and animals, in addition to suspended organic and inorganic matter [5]. Low levels of turbidity of water indicate a healthy, well-functioning aquatic ecosystem. However, higher levels of turbidity cause several problems for aquatic system. Increased turbidity may block out the light needed by submerged aquatic organisms. High levels of turbidity also can elevate surface water temperatures above normal because suspended particles near the surface facilitate the absorption of heat from sunlight. A turbid water body contains low dissolved oxygen during the high surface water temperature caused by suspended particles [9].

3 Different Water Pollutant

The Nile River receives its water from the tropical headwaters in Central Africa and Ethiopia. Egypt, the downstream country, is located in an arid climatic zone, and it depends absolutely on water from a single source, the Nile water. Most of the populated centers conduct industrial activities and agricultural activities on both sides of the Nile. Consequently, the Nile currently receives enormous amounts of agricultural wastewater that carry various chemical pollutants related to the widespread use of fertilizers and pesticides. Besides great quantities of industrial, municipal, and domestic wastes, storm water runoff is drained directly or indirectly into the Nile [13, 14]. The Nile River receives different pollutants from different sources, and two of the most used pollutants (in Ethiopia, Sudan, and Egypt) are pesticides and herbicides. Pesticide residues are mainly organochlorine and organophosphorous compounds in various aquatic ecosystems and have been studied by several investigators [15, 16]. Sallam et al. [14] recommended the need to improve environmental protection measures in order to reduce the bioaccumulation of these compounds through food ingestion. Furthermore, regular monitoring is warranted for the sustainable use of persistent pesticides in agriculture and to evolve a strategy to manage the environmental hazards due to these pesticides. The obtained results showed that organochlorine content in sediment collected from the Nile River sites located in Upper and Mid Egypt is higher than in sediments collected from Greater Cairo and Delta sites. In contrary, organophosphorous residues were found in greater quantities in some North Egypt locations.

4 Impacts of Industrial Wastewater on Water and Fish Quality of the Nile River

The Nile River receives many types of pollution through different routes and sources. Industrial effluents represent the major pollutant source for freshwater of the Nile River. It was reported by El-Tras et al. [17] that the risk of water pollution with toxic chemicals was not limited only to public health but extended to zoonotic diseases. The expansion of factories and companies constructed in different countries along the Nile River basin has severe impact on the quality of the rive Nile water. In Egypt, industrial pollution sources along the Nile River in Upper Egypt area are mainly agro-industrial and small private industry. Sugar cane industries significantly influence Nile water quality at Upper Egypt-South zone, while hydrogenated oil and onion-drying factories influence Nile water quality at Upper Egypt-North zone [18]. The area of Greater Cairo encompasses many industrial and commercial activities. Heavy industry is located around south of Cairo and north of Cairo. Many small industries and some heavy industries are randomly located throughout the city. In addition, the tanning industry causes local contamination problems. Harris and Abdel Nasser [19] reviewed the pollution sources and their effect on water quality in Egypt. Their review included 23 chemical industries, 27 textile and spinning industries, 7 steel and galvanizing industries, 32 food-processing industries (including a brewery), 29 engineering industries, 9 mining and refraction industries, and petrol and car service stations. In addition, bakeries, marble and tile factories, and tanneries are located in South Cairo. The Nile River is divided into two branches in North Cairo, namely, Rosetta and Damietta branches. The Rosetta branch receives heavily polluted water by industrial and domestic sewage. The wastes in the drains contain high levels of suspended and dissolved solids, oil, grease, nutrients, pesticides, and organic matters. It is suspected that toxic substances are present as well. Kafr El-Zayat City which is located at the Rosetta branch has many factories and companies such as oil and soap, fertilizers, pesticides, and the sulfur industry (El-Malh and Soda, El-Malyia, and El-Mobidat factories) which have impact on water quality [18]. The wastes in the drains contain high levels of suspended and dissolved solids, oil, grease, nutrients, pesticides, and organic matters. Therefore, the water quality deterioration is pronounced; the high values of water turbidity were recorded at Kafr El-Zayat, also high values of BOD, phosphates, and TDS [20]. The Damietta branch also receives polluted water of a number of agricultural drains; the fertilizer company is considered as the major point source of industrial pollution at Damietta branch. Alexandria area is a major industrial center including paper, metal, chemical, textile, plastic, pharmaceutical, oil and soap, and food processing. The industries discharge their effluents mainly to Lake Mariut and partially to the sewerage network [21]. Osman and Kloas [22] found higher mean value of conductivity, alkalinity, COD, NH_3, NO_3, TS, SO_4, Cl, and orthophosphate and trace metals in the water, sediments, and fish tissues collected from Damietta and Rosetta sites; comparing to the other sites prove the presence of large quantities of organic and inorganic pollutants in Rosetta and Damietta water. They also studied some physical and chemical parameters of the water samples collected from six sites along the whole course of the Nile River from its spring at Aswan to its estuary at Damietta and Rosetta branches (Table 1). The results showed that the chemical oxygen demand (COD) and total organic compounds (TOC) remarkably fluctuated with a slight increase from Aswan to Rosetta. Total solid showed a remarkable increase from Aswan to Damietta and Rosetta. Water hardness was slightly increased from Aswan to Rosetta and Damietta. The results correlated with the toxicity water quality of the Nile River with the quality of fish, including the accumulation of some metals in the fish tissues (for other more water characteristics, see Table 1). Also, Tayel et al. [23] detected histopathological and hematological responses to freshwater pollution in the Nile catfish *Clarias gariepinus*. They attributed these changes to the fact that the water of the two branches of the Nile receives high concentrations of organic and inorganic pollutants from industrial, domestic, as well as agricultural wastewater. The heavy metal residues in the tissues of *Clarias gariepinus* exhibited different patterns of accumulation and distribution among the selected tissues and localities. In fish, gills are considered to be the dominant site for contaminant uptake because it maximizes absorption efficiency from water [24]. Contrary to the above results, Osman and Kloas [22] found that the liver was the site of maximum accumulation for the elements, while muscle was the overall site of least metal accumulation. Ikem et al. [25] attributed the higher levels of trace elements in liver relative to other tissues to the strong coordination of metallothionein protein with these elements. The fish which accumulate considerable amounts of pollutants from Nile water pass this impact on human health. Gaber et al. [26] studied the effect of the water quality of the El-Rahawy drain at El-Rahawy village, Egypt, on the African catfish *Clarias gariepinus*' blood, biochemical parameters, and histology of

Table 1 Mean and SD of some physical and chemical parameters of the water samples collected from six sites along the whole course of the Nile River from its spring at Aswan to its estuary at Damietta and Rosetta branches (Osman and Loas [22] after permission)

	Locality						
	Aswan	Kena	Assiut	Beni Suef	Damietta	Rosetta	Permissible limit
Parameter (unit)	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	
pH (unit)	7.8 ± 0.248	8.01 ± 0.405	8.15 ± 0.187	8.27 ± 0.273	8.40 ± 0.442	8.223 ± 0.449	7–8.5
Conductivity (Ms cm^{-1})	0.25 ± 0.029	0.27 ± 0.0701	0.28 ± 0.086	0.33 ± 0.0722	0.37 ± 0.099	0.57 ± 0.115	–
Temperature (°C)	22.68 ± 2.218	23.71 ± 3.152	23.33 ± 4.671	23.64 ± 4.239	25.29 ± 5.661	24.52 ± 4.441	Over 5°C
Chemical oxygen demand (ppm)	10.58 ± 3.616	9.16 ± 3.0419	10.63 ± 2.179	7.87 ± 2.153	8.59 ± 2.509	18.00 ± 10.375	10
Total organic carbon (ppm)	5.65 ± 2.876	5.89 ± 1.925	5.73 ± 0.918	4.93 ± 2.575	5.20 ± 2.635	8.61 ± 6.055	–
Total solid (ppm)	198.87 ± 14.08	212.66 ± 23.70	227.75 ± 16.297	259.5 ± 44.33	305.25 ± 55.959	411.25 ± 85.66	500
Hard (ppm)	123.7 ± 15.756	134.4 ± 23.26	140.36 ± 29.316	127.56 ± 23.84	147.83 ± 17.101	162.25 ± 25.53	–
Magnesium (ppm)	11.86 ± 4.672	14.97 ± 7.989	14.34 ± 7.52	13.92 ± 6.292	15.32 ± 5.255	16.43 ± 3.887	–
Calcium (ppm)	29.89 ± 6.423	25.76 ± 4.1015	29.21 ± 7.062	28.12 ± 7.24	34.05 ± 10.639	38.31 ± 12.3742	–
Ammonia (ppm)	0.105 ± 0.158	0.008 ± 0.00145	0.019 ± 0.011	0.012 ± 0.0098	0.044 ± 0.0487	0.14 ± 0.091	0.5
Nitrate (ppm)	0.80 ± 0.396	0.76 ± 0.3868	0.50 ± 0.205	0.72 ± 0.627	1.134 ± 1.131	2.04 ± 2.271	45
Chlorides (ppm)	7.052 ± 1.443	8.56 ± 1.896	10.03 ± 2.58	15.28 ± 5.103	22.41 ± 4.929	40.54 ± 6.722	–
Fluoride (ppm)	0.28 ± 0.146	0.31 ± 0.1383	0.38 ± 0.163	0.31 ± 0.125	0.30 ± 0.0971	0.37 ± 0.0737	0.5
Ortho phosphate (ppm)	0.01 ± 0.0198	0.03 ± 0.0381	0.09 ± 0.090	0.03 ± 0.034	0.13 ± 0.066	0.21 ± 0.1871	–
Sulfate (ppm)	34.16 ± 13.299	45.33 ± 15.37	47.95 ± 14.11	45.25 ± 15.81	51.00 ± 12.759	68.12 ± 11.4261	200
Alkalinity (ppm)	96.2 ± 31.43	103.49 ± 25.943	102.93 ± 54.427	98.26 ± 25.86	115.24 ± 38.266	124.25 ± 47.831	20–150
Phenol (ppm)	0.01 ± 0.0227	0.01 ± 0.0198	0.01 ± 0.0157	0.01 ± 0.0098	0.02 ± 0.0178	0.04 ± 0.0227	0.02
Pb (ppm)	0.012 ± 0.0154	0.021 ± 0.0143	0.024 ± 0.017	0.016 ± 0.009	0.03 ± 0.041	0.06 ± 0.078	0.05
Cd (ppm)	0.004 ± 0.0046	0.002 ± 0.0024	0.006 ± 0.007	0.002 ± 0.002	0.02 ± 0.023	0.012 ± 0.0179	0.1
Zn (ppm)	0.21 ± 0.1736	0.12 ± 0.1017	0.30 ± 0.465	0.34 ± 0.457	0.45 ± 0.689	0.69 ± 0.952	1

(continued)

Table 1 (continued)

Parameter (unit)	Locality						
	Aswan	Kena	Assiut	Beni Suef	Damietta	Rosetta	Permissible limit
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	
Cu (ppm)	0.030 ± 0.0272	0.022 ± 0.0245	0.030 ± 0.0261	0.031 ± 0.0276	0.032 ± 0.0321	0.054 ± 0.0278	1
Cr (ppm)	0.003 ± 0.0025	0.006 ± 0.0058	0.005 ± 0.0057	0.006 ± 0.0050	0.045 ± 0.0643	0.088 ± 0.1549	0.05
Fe (ppm)	0.19 ± 0.176	0.22 ± 0.1955	0.34 ± 0.3265	0.46 ± 0.3937	0.41 ± 0.2733	0.49 ± 0.4494	1
Hg (ppm)	0.0000 ± 0.001	0.0004 ± 0.0005	0.0005 ± 0.0011	0.0000 ± 0.0009	0.002 ± 0.0017	0.003 ± 0.0013	0.001
Mn (ppm)	0.033 ± 0.0277	0.0651 ± 0.0685	0.045 ± 0.021	0.058 ± 0.060	0.071 ± 0.0851	0.099 ± 0.1466	0.5

digestive tract, testis, and ovaries. They found that badly polluted and poor water quality increased blood parameters in fish caught from El-Rahawy at the Nile River because it receives greater agricultural, industrial, and domestic wastes.

5 Effect of Heavy Metals on the Nile River Water

The Nile River is facing environmental and public health problems of water pollution which affects water quality and influences the balance of the whole ecosystem [27]. Water quality of the Nile River and trace elements of the water, sediments, and fish tissues were investigated [28]. The rapid progress in industry led to the release of heavy metals in the ecosystem and especially the aquatic ecosystem. Heavy metals come from industrial wastewater and also municipal wastewater, and the accumulation of these metals in the Nile River water affects the quality of the water. The iron and steel industry releases lead and zinc into the Nile River, while manganese comes from the coke industry [29]. El Bouraie et al. [30] monitored the distribution of heavy metals (Al, Ba, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, and Zn) in the Nile River water and the bed sediments of Rosetta branch and studied the impacts of heavy metals on the water quality. The occurrence of heavy metals in waters and biota indicates the presence of natural or anthropogenic sources leading to changes in water quality. Heavy metals in the Nile River and its branches and canals affect the water quality as well as the fish which represent the main food for many countries of the Nile basin. Heavy metal pollution has been described in the Nile River and associated irrigation canal systems of the Nile Delta, particularly in suburban areas due to the industry surrounding the city of Cairo [31].

Some heavy metals are essential to biochemical processes in most aquatic microorganisms especially algae. However, at high concentrations, these metals can be highly toxic to aquatic organisms. These metals may be toxic to humans, if they are ingested directly in water or if they accumulate in organisms that are consumed by humans such as fish. Bakhiet [32] determined the levels of some heavy metals in the water of White Nile Khartoum City, Sudan, as well as in the various organs of tilapia species (*Oreochromis niloticus*). She found that lead (Pb), cadmium (Cd), and copper (Cu) were concentrations varied according to the organ or tissue analyzed. The higher recorded concentration was in the gills followed by the liver, the kidney, and finally the muscles.

6 Effect of Organic Pollution on the Nile River Water

The Nile River is subjected to different organic pollution levels from human activities along its full course from High Aswan Dam into Damietta and Rosetta branches which ended to the Mediterranean Sea [33]. It is evident that the two

Fig. 1 Boat transportation at Luxor (Upper Egypt) (the photo was picked up by M. El-Sheekh)

branches are more polluted with organic pollutants in Delta region where the industrial and agricultural activity increase due to the increase of population. The widespread in building the industrial factories along the Nile River valley affected greatly the water quality of the river by adding organic matters and suspended materials [34]. These industries include chemicals, fertilizers, insecticides, sugar, aluminum, steel, soap, and paper. Oil spills from navigation and other activities such as tourism in Upper Egypt also contribute to the organic water pollution (Fig. 1). Ewida [35] studied oil spills impact on water quality and the microbial community on the Nile River, in Egypt. He found that the pH values, EC, and TDS of water of the Nile River were not affected, while oil and grease, BOD and COD increased with a predominance of biodegrading bacteria during the study period of oil spills (Table 2). Oil and grease are toxic to aquatic life and cause oxygen depletion in the river through decay and degradation. In their study to investigate the organic contaminants present in the Nile River, El-Sayed and Ouf [36] concluded that environmental hydrocarbon pollution in the Nile River comes from middle petroleum distillate fractions used in shipping activities.

Besides the industrial wastes, the agricultural wastewater that carries various chemical pollutants related to the widespread use of fertilizers and pesticides drained directly or indirectly into the Nile affecting its water quality and biodiversity of aquatic organisms [13]. Pesticides are divided to many classes, of which the most important are organochlorine and organophosphorous compounds.

Table 2 Water quality assessment in the Nile River in three different oil spill cases ([35] after permission)

Parameter	Unit	Helwan case 2008		Aswan case 2010		Nag Hammadi case 2012		Low 48/article 60
		Helwan normal Nile water	Helwan polluted water	Aswan normal Nile water	Aswan polluted water	Nag Hammadi normal Nile water	Nag Hammadi polluted water	
Oil and grease	mg/l	0.3	426	0.07	109	0.09	2.92	0.1
pH		7.76	7.68	7.51	7.65	7.62	7.96	7–8.5
EC	mmhos/cm	0.366	0.394	0.286	2.89	0.299	0.311	
TDS	mg/l	234	252	225	238	222	227	500
BOD	mg/l	15	130	5	76	4	30	6
COD	mg/l	18	550	7	230	7	98	10
Total coliform	CFU/100 ml	8,000	5,000	900	600	2,800	1,600	
Fecal coliform	CFU/100 ml	1,000	600	20	8	500	200	

Organochlorine compounds, i.e., hexachlorocyclohexanes (HCHs), DDT and its metabolites, endosulfan, and endosulfan sulfate, are ubiquitous, persistent, toxic, and bioaccumulative in nature. These compounds exert chronic toxic effects on wildlife and humans [37]. Organochlorine pesticides are still used in the countries of the Nile River basin such as Ethiopia and Sudan. Therefore, they are considered as important environmental hazardous compounds because of their bioaccumulation in the lipid component of biological species and their resistance to degradation [38]. The bioaccumulation of these toxic organic compounds that persist in the environment through the food web poses a risk of causing adverse effects to human health and the environment. Aerobic microbes break down the complex organic compounds into simple products such as carbon dioxide, water, phosphate, and nitrate. As a result of this biodegradation, the dissolved oxygen may be consumed affecting the life-forms in the aquatic system. The organic particles in the water may harbor pathogenic bacteria which may affect water quality especially if the water is used for drinking [39]. The residues of organochlorine insecticides and polychlorinated biphenyls (PCBs) in the water of the Nile River and its branches were analyzed by El-Gendy et al. [40]. They found high concentrations of these organic compounds at Kafr El-Zayat City, and they indicated that the Rosetta branch was more polluted than the Damietta branch. This may be due to the large number of industrial factories at this branch. El-Kabbany et al. [41] recorded 16 organochlorine pesticides in the water samples collected from the Nile River representing different chemical classes. The most common pesticides were endrin, total BHC, total DDT (1,1,1-trichloro-2,2-bis(4-chlorophenyl)ethane), endosulfan, heptachlor epoxide, and heptachlor. Malhat and Nasr [42] monitored 14 organophosphorus pesticides in water samples from different tributaries of the Nile River in Egypt. All these organic pollutants including organic matters or pesticides affect the water quality of the Nile River either directly by altering the physical and chemical characters of the water or by an indirect route through the accumulation of these pesticides in the tissues of the fish which is then consumed by humans and thus affects health and environment.

7 Algae and Water Quality

Algae are a diverse group of photosynthetic plants which represent the main component of any freshwater body. Algae represent an important step in the food chain in any aquatic ecosystem. Algae are the main food for fish. The excessive release of pollutants leads to phytoplankton blooms and to the disruption of the structure and functioning of aquatic ecosystem [43, 44]. Eutrophication means the overload of the aquatic environment with nutrients, and this affects aquatic habitats such as rivers and lakes. The main source of nutrient enrichment of the aquatic ecosystem is fertilizers from agricultural runoff. This causes phytoplankton to grow and reproduce more rapidly, resulting in algal blooms. The algal bloom disrupts the water quality parameters according to the type of algae. As a result of heavy growth, the algae may use up all the oxygen in the water, limiting the content available for other species. This results in the death of many aquatic organisms such as fish. The bloom of algae may also block sunlight from photosynthetic marine plants under the water surface. Some algae produce toxins that are harmful to higher forms of life. This can cause problems along the food chain and affect any animal that feeds on them. Toxic algal blooms disrupt tourism due to foul odors and unsightly views, and poisoned fish and shellfish adversely affect recreational and commercial fisheries [42]. Eutrophication may also trigger toxic algal blooms like red tides, brown tides, and the growth of toxic algae that can release very powerful toxins into the water, causing bleeding sores on fish, and even cause fish deaths [45].

The water quality of the Nile River can be affected by the release of some chemicals from algae that cause odor or taste to the water. It was found that more than 60 algal species produce substances that change the odor and taste of water [46]. Palmer [47] compiled a list on algae-related problems in public water supplies (Table 3). In the last few decades, some researchers made progress in the identification of chemistry of odor- and taste-causing substances produced by algae [48]. Generally, such substances are released during the growth phase of algal cell development. Some of the odorous metabolites produced by algae have been identified as alcohols, esters, aldehydes, ketones, and acids. Safferman et al. [49] were the first to evidence that geosmin ($C_{12} H_{22} O$) is produced by algae. This is the substance first isolated by Gerber and Lechevalier [50]. Geosmin, chemically known as 1,2,7,7-tetramethyl-2-norborneol, is an organic compound that is responsible for the earthy smell often associated with fresh-turned dirt. In water sources, this compound is produced by some species of cyanobacteria (blue-green algae). The presence of this compound in drinking water and in freshwater in general which is mainly supplied from the Nile River is of great concern, and it is difficult to remove this compound in treatment plants. The potential utility of taste and odor as a signal of toxicity is complicated by the fact that a musty smell doesn't necessarily mean treated tap water is unsafe. Treatments that successfully remove cyanotoxins may not eliminate geosmin [51].

7.1 Algae as Indicators of Water Pollution and Water Quality

Algae are valuable indicators of ecosystem conditions because they respond quickly both in species composition and densities to a wide range of water conditions due to changes in water chemistry. Algae have recently been used as biological indicators in water quality assessments. The use of algal parameters in identifying various types of water degradation is essential and complementary to other environmental indicators [52]. Algae are widely used for water quality assessment because they have rapid reproduction rates and very short life cycles, making them valuable indicators of short-term impacts. Algae are primary producers which are directly affected by physical and chemical factors. Some algae are sensitive to environmental and natural disturbances, and they readily accumulate

Table 3 Taste and odor algae, representative species [47]

Blue-green algae	**Diatoms**
Anabaena circinalis	*Asterionella gracillima*
Anabaena planctonica	*Cyclotella compta*
Anacystis cyanea	*Diatoma vulgare*
Aphanizomenon flos-aquae	*Fragilaria construens*
Cyclindrospermum musicola	*Stephanodiscus niagarae*
Gomphosphaeria lacustris	*Synedra ulna*
Oscillatoria curviceps	*Tabellaria fenestrata*
Rivularia haematites	**Different flagellate algae**
Green algae (nonmotile)	*Ceratium hirundinella*
Chara vulgaris	*Chlamydomonas globosa*
Cladophora insignis	*Chrysosphaerella longispina*
Cosmarium portianum	*Cryptomonas erosa*
Dictyosphaerium ehrenbergianum	*Dinobryon divergens*
Gloeocystis planctonica	*Euglena sanguinea*
Hydrodictyon reticulatum	*Glenodinium palustre*
Nitella gracilis	*Mallomonas caudate*
Pediastrum tetras	*Pandorina morum*
Scenedesmus abundans	*Peridinium cinctum*
Spirogyra majuscula	*Synura uvella*
Staurastrum paradoxum	*Uroglenopsis americana*
	Volvox aureus

pollutants [52, 53]. Algae growth and forecasting movement in river systems is important for operational managers responsible for the distribution and supply of potable water [54]. Diatoms are silicified algae which exist in all aquatic habitats. Diatoms are widely used as indicators for water quality and the pollution status of the freshwater of rivers and lakes. Diatoms can tolerate different ecological conditions and thus provide a good indicator for environmental changes [53]. Periphyton is a kind of algae which can be a tool for biologically monitoring water quality [55]. Periphyton algae exhibit high diversity, are a major component in energy flow and nutrient cycling in aquatic ecosystems, and have many characteristics of community structure and function [56]. Algae can grow in abundance to the extent that they change the color of water, which can significantly impair the recreational uses of aquatic systems [49]. One of the effective methods for using algae to assess water quality is depending on the indicator species concept (Saprobien system). The Saprobien system is widely used in municipal and wastewater monitoring [57] and discriminates between polluted and clean streams [58]. Algae have the ability to exist and grow in polluted and unpolluted waters, and therefore, they used to determine the quality of water in rivers and lakes. Algae change will affect the lower level of the food chain on the higher level [59]. Furthermore, algae can be used to assess the degree of pollution [60]. Jafari and Gunale [61] stated that biological assessment is a useful approach for assessing the ecological quality of aquatic ecosystems. They collected algal and water samples from three sites of the River Mutha (Pune, India). They determined the most pollution-tolerant genera and species of four groups of algae. They used Nygaard's and Palmer's biotic indices for the assessment of quality of the river. Phytoplankton was used as indicator of water quality. The algal flora of polluted water bodies shows the dominance of blue-green algae (cyanobacteria) like *Oscillatoria*, *Lyngbya*, *Anabaena*, and *Microcystis* and diatoms like *Navicula*, *Nitzschia*, *Synedra*, and *Gomphonema*, and the green algae, *Pandorina*, *Scenedesmus*, *Stigeoclonium*, *Ankistrodesmus*, and *Chlamydomonas*, also occur abundantly and frequently (Fig. 2). Jafari [62] used Palmer's pollution-tolerant algae indices and Nygaard's indices and phytoplankton data for describing eutrophic conditions in Babolrood River. He also stated that phytoplankton can be used as indicator for water quality especially when it reflects the saprobic condition. He found that upstream to downstream of river which receives large inputs of nutrients such as phosphate and nitrate was abundant by species like *Euglena viridis*, *E. gracilis*, *Oscillatoria limosa*, *O. chlorine*, *O. tenuis*, *Stigeoclonium tenue*, *Scenedesmus quadricauda*, *Nitzschia acicularis*, *N. palea*, etc., while the upstream stations are characterized by abundance of green algal flora like *Zygnema pectinatum*, *Z. quadrata*, *Spirogyra singularis*, *Mougeotia gracillima*, *Euastrum denticulatum*, *E. irregulare*, *Staurastrum megacanthum*, etc. which mostly grow in natural waters having low pollutants. He also concluded that algae groups can be used as biological index of water quality. The trophic state indices are considered as a good index for assessing eutrophication.

7.2 Algal Blooms

Algal blooms occur in surface waters when light, temperature, and nutrient conditions are favorable for one type of algae over another. This combination allows one alga to become dominant. The ecological imbalance caused by pollution may be the trigger. The discharge of nitrates, organic phosphorus, and ammonia into the water body from water treatment plants, from industrial sector, or from cattle feed and fertilizer from agricultural fields supports the algal blooming. The conditions favorable to blooms are seasonal. Spring and winter conditions favor golden brown algae and fishy, cucumber odors. Summer and fall conditions favor geosmin and musty odors. Generally, the most common bloom month is September. In addition to the algae that change odor and taste of water, some other blue-green algae (cyanobacteria) when it blooms produce some toxins called cyanotoxins that can be very harmful for biota, animals, and humans by deteriorating the water quality.

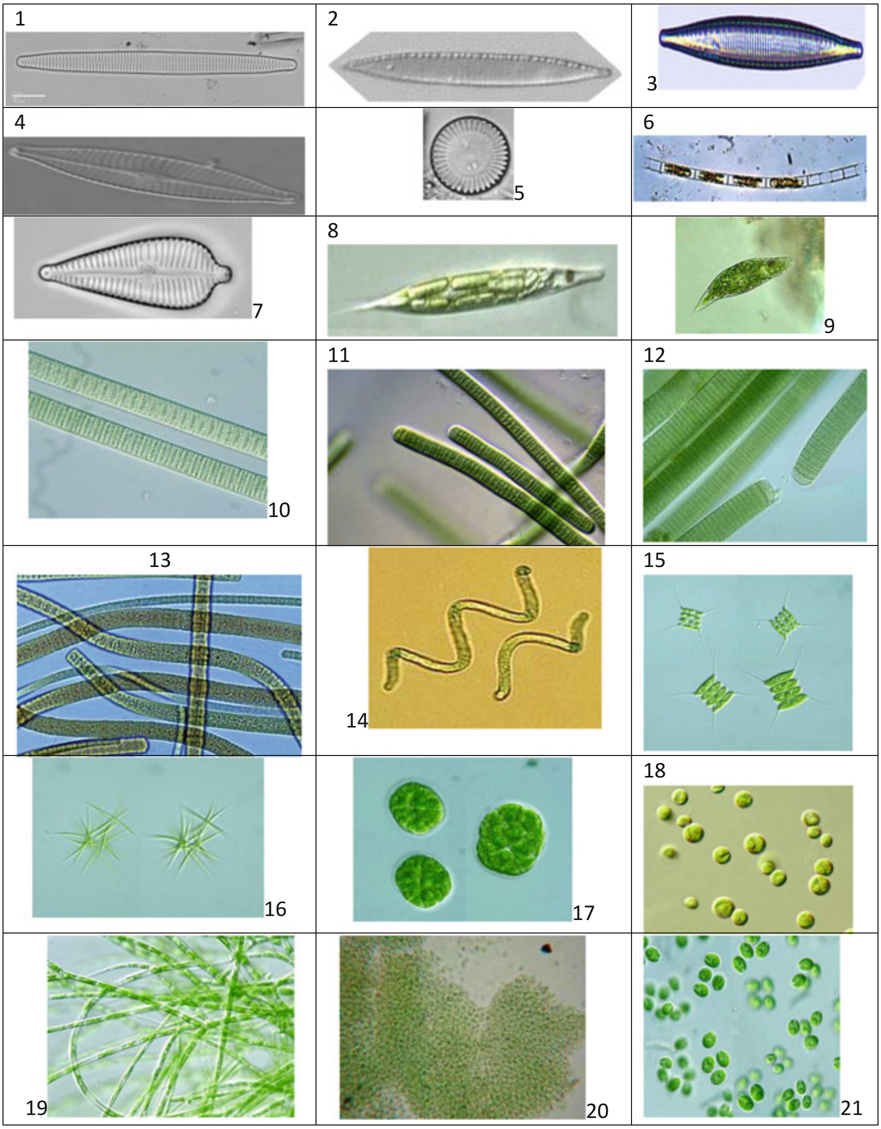

Fig. 2 Algae as indicators of water pollution and water quality. (*1*) *Synedra ulna*, (*2*) *Nitzschia palea*, (*3*) *Nitzschia cryptocephala*, (*4*) *Navicula cryptocephala*, (*5*) *Cyclotella meneghiniana*, (*6*) *Melosira islandica*, (*7*) *Gomphonema parvulum*, (*8*) *Euglena acus*, (*9*) *Euglena viridis*, (*10*) *Oscillatoria limosa*, (*11*) *Oscillatoria tenuis*, (*12*) *Oscillatoria princeps*, (*13*) *Oscillatoria putrida*, (*14*) *Arthrospira jenneri*, (*15*) *Scenedesmus quadricauda*, (*16*) *Ankistrodesmus falcatus*, (*17*) *Pandorina morum*, (*18*) *Chlorella vulgaris*, (*19*) *Stigeoclonium* sp., (*20*) *Microcystis aeruginosa*, (*21*) *Chlamydomonas reinhardtii*

7.3 Cyanotoxins

Despite the fact that the Nile River is the main source of drinking water in Egypt, it is exposed to several sources of pollution, including industrial, municipal, and agricultural wastes. This pollution resulted in increased nutrient concentrations such as phosphorus and nitrogen, leading to harmful cyanobacterial blooms (HCB) [63]. Most studies on the occurrence of cyanobacteria in the Nile River water demonstrated the presence of toxin-producing species and their toxins in the river especially *Microcystis aeruginosa*. These studies were carried out in the presence of toxic species and their cyanotoxins in the southern part of the Nile River [64, 65] and northern part of the Nile Delta [66]. These blooms and their toxins can deteriorate the water quality of drinking water treatment plants (WTPs) taking water from the Nile River source.

Cyanotoxins are toxic substances secreted by the cyanobacteria (blue-green algae) which affect water quality. Most toxic cyanobacterial species belong to the genera, *Anabaena*, *Aphanizomenon*, *Cylindrospermopsis*, *Microcystis*, *Nodularia*, *Nostoc*, and *Oscillatoria* [67]. Carmichael [68] stated that cyanobacteria produce two main types of toxins: cyclic peptide hepatotoxins and alkaloid neurotoxins. The hepatotoxic cyclic peptides called microcystins (MCYSTs) are commonly found in freshwaters, and they are cyclic heptapeptides produced by several species of cyanobacteria such as *Microcystis*, *Anabaena*, and *Oscillatoria* [69]. Mohamed et al. [65] investigated the microcystin (MCYST) concentrations in the Nile River and irrigation canal sediments in Egypt. They concluded that cyanobacterial toxins in freshwater sediments of the Nile River can affect benthic organisms inhabiting these sediments, and thus, it should be considered during biological monitoring of rivers and streams. Mohamed et al. [70] described the species composition and toxicity of benthic cyanobacteria forming mats on the Nile River and irrigation canal sediments in Egypt. A total of 19 species of cyanobacteria were isolated from these mats during this study. They studied the toxicity of the extracts of these species using *Artemia salina* assay, enzyme-linked immunosorbent assay (ELISA), and mouse bioassay. Mohamed et al. [70] suggested that benthic cyanobacterial species should be considered during monitoring of toxic cyanobacteria in water sources. These benthic cyanobacteria could produce anatoxins, microcystins, or saxitoxins [71, 72]. Mohamed et al. [73] investigated the occurrence of cyanobacteria and their microcystin (MC) toxins in the Nile River water of Damietta as a source of water treatment plant (WTP). This study was done during warm months, and they also evaluated the removal efficiency of both cyanobacterial cells and MCs by conventional methods used in the water treatment plant studied as a representative of Egyptian drinking WTPs. The Nile River is the main source of drinking water in the countries of the Nile basin especially Egypt. The water quality of the water can be deteriorated by different pollutants such as cyanotoxins. Dittmann and Wiegand [74] stated that the presence of some toxic cyanobacterial blooms in drinking water sources can deteriorate the water quality affecting animal and human health through potent cyanotoxins. These cyanotoxins include

Table 4 Common toxin-producing cyanobacteria and their health effects

Cyanobacteria-producing toxin	Cyanotoxin	Affected organ	Health effects
Microcystis *Anabaena* *Planktothrix* *Anabaenopsis* *Aphanizomenon*	Microcystin-LR	Liver	Abdominal pain Vomiting and diarrhea Liver inflammation and hemorrhage Acute pneumonia Acute dermatitis Kidney damage
Cylindrospermopsis *Aphanizomenon* *Anabaena* *Lyngbya* *Rhaphidiopsis* *Umezakia*	Cylindrospermopsin	Liver	Abdominal pain Vomiting and diarrhea Liver inflammation and hemorrhage Acute pneumonia Acute dermatitis Kidney damage
Anabaena circinalis *Aphanizomenon flos-aquae*	Saxitoxins	Peripheral nerves and skeletal muscles	Pharmacological effect on nerve axon membranes Paralysis, respiratory depression, and respiratory failure
Anabaena *Planktothrix* *Aphanizomenon* *Cylindrospermopsis* *Oscillator*	Anatoxin-a	Nervous system	Tingling, burning, numbness, drowsiness, incoherent speech, salivation, respiratory paralysis leading to death
Cylindrospermopsis *Lyngbya* *Anabaena*	Cylindrospermopsin Debromoaplysiatoxin	Skin	Itchy edematous eyelids associated with conjunctivitis Dermatitis Allergy Generalized urticarial rash

Source: Environmental Protection Agency (EPA) [80] after modification

hepatotoxins (microcystins, nodularin, cylindrospermopsin), neurotoxins (anatoxins and saxitoxins), and skin and gastrointestinal irritants [75]. Common toxin-producing cyanobacteria and their health effect source are presented in Table 4.

The distribution and occurrence of cyanobacterial blooms in eutrophic freshwater bodies such as lakes and rivers are determined by many physical and chemical factors. The environmental conditions which affect toxic cyanobacterial blooms are temperature, pH, light intensity, and nutrient load concentration such as phosphorus and nitrogen as well as some microelements which are essential for overgrowth of cyanobacteria-producing toxins [76–78]. In addition to the above abiotic factors, there are some biotic factors such as grazing of other phytoplankton by zooplankton [79].

8 Impacts of Fish Cages on the Water Quality of the Nile River

Pollution of the Nile River by inorganic and organic pollutants is an environmental problem posing a serious threat to the survival of fish. Degefu et al. [81] studied the potential impact of Nile tilapia (*Oreochromis niloticus*) cage culture on the water quality of two Ethiopian small water bodies, one located in the highlands (Yemlo) and the other in the Great Rift Valley (Allage). They also studied the pelagic community composition and the difference between the cages and open water in relation to water quality criteria. The study attributed the changes in such water quality to the intensive inputs of fish waste and leftover fish feed.

By assaying the physical parameters and dissolved inorganic nutrient concentrations, they concluded that no significant differences were found between the cages and open water of the Nile River. However, the dissolved oxygen and ammonium nitrogen were lower in open water and higher in the cages. In the Nile River and its branches in Egypt, fish farming in floating cages either legal or illegal has been established for the production of protein required by the expanding population. Fish farming in cages is an easy and simple technique and economically feasible without any net increase in water consumption [82]. Fish farming in cages has some disadvantages; it may produce some nutrient wastes such as ammonia, nitrates, and phosphorus. These wastes deteriorate the water body. Furthermore, the fish heavily consume the dissolved oxygen leading to low oxygen content in the surrounding areas [83]. Beveridge [84] recorded a decrease in dissolved oxygen (DO) and increases in biological oxygen demand (BOD) and nutrients (phosphorus, organic and inorganic nitrogen, and total carbon) in the water column around fish farms.

The Egyptian General Authority for Fish Resources Development of the Ministry of Agriculture is responsible for the implementation of Law No. 124/1983 and organizes fishing, fish farming, and the aquaculture to conserve water quality from deterioration [85].

There are possible risks of fish cages on the water quality of the Nile River and its branches either Damietta or Rosetta. The aquaculture drainage water may contain residues of hormones, pesticides, herbicides, antibiotics, or chemical compounds associated with fish treatments; this can cause serious problems to the ecosystem and the human health. Nutrients in the effluent waters from floating fish cages are discharged in the form of NH_4. However, during the process of equilibrium, if NH_3 exceeds to a certain level, it can be toxic to the human and other organisms. The overstocking of fish in the cages may cause severe negative impacts on the water and sediment quality [80]. Fish farming is now considered a good source for protein production and as a source of income for the community; however, its wide, random, and uncontrolled spread poses a negative effect on the water quality of the Nile River and on human health. Fish farming in cages needs better management and supervision to limit the environment's degradation through controlling the farming intensity and monitoring the types of feed for fish, in addition to imposing aeration practices for these cages and a frequent follow-up and monitoring of the farming process.

9 Human Impacts on the Nile River Water Quality

Human activities and the increased population living around the basin have caused different pollutants to enter the aquatic system of the river. In order to monitor pollutants, test organisms are needed in which these compounds can be traced at the tissue level. Aquatic animals, aquatic plants, various fish, shellfish, and algae are used as indicators for pollution and water quality [86].

Construction of the Aswan High Dam has had a dramatic effect on the ecosystem of the Nile River. Before construction, the annual Nile flood delivered about 7–11 × 103 t of biologically available phosphorus (P), at least 7 × 103 t of inorganic nitrogen (N), and 110 × 103 t of silica (Si) to the Mediterranean coastal waters of Egypt. Phosphorus, nitrogen, and silicon are important nutrients for algal bloom stimulation of diatoms which supported a productive fishery. The fishery collapsed after the closure of the dam in 1965 because the flow from the Nile was reduced. After 15 years, the fishery began a dramatic recovery during the 1980s. This dramatic increase was due to the increasing human population, increasing fertilizer use, expanded agricultural drainage, and the extensions of urban water supplies and sewage collection systems. Human sewage and agricultural drainage now support the fertility once provided by the Nile. This is due to the anthropogenic contribution of nutrients (P and N but not Si) to the eutrophication of the Nile River water [87].

After construction of the High Aswan Dam, the water quality of the Nile became primarily dependent on the quality and ecosystem characteristics of the Lake Nasser reservoir and less directly dependent on the water quality of the upper reaches of the Nile [18]. The release of water from the Lake Nasser generally exhibits the same seasonal variation and the same overall characteristics from 1 year to another.

The tremendous changes in the downstream of the Nile River water quality are mainly due to the hydrodynamic regime of the river, regulated by the Nile barrages; agricultural, domestic, and industrial waste discharges; and oil waste from boats. The increase in these changes is more pronounced as the river flows through the densely populated urban and industrial centers of Cairo and the Delta region [88].

The African Great Lakes are located at eastern part of Africa. These lakes include Lake Victoria, Tanganyika, Malawi, Turkana, Albert, Kyoga, Kivu, Edward, and other small lakes. Agricultural activities, deforestation, and de-vegetation of the catchment areas have increased siltation and led to loss of suitable habitats and biodiversity in these lakes. There is an increase in eutrophication in the lakes due to nutrient inputs from agriculture, sewage, and industrial discharges and combustion processes. These pollutants in addition to industrial waste discharge, mining, organic chemicals such as pesticides, and oil spills increased threats of water toxicity and hence deteriorate the water quality

[89]. Nowadays, it is necessary and urgent to plan to secure water quality from deteriorating through the implementation of projects and strategies supporting water management.

10 Water Quality and Pollution in the Nile River Basin of Egypt

The input of pollutants to the water of the Nile River from different countries such as Ethiopia, Sudan, and Egypt affects the water quality as well as the diversity of the microorganisms inhabiting the water. It also affects the fish which is considered the main food for people inhabiting the two banks of the river and its channels. In spite the discharge of different kinds of pollutants into the Nile River, the water quality does not yet exhibit pollution levels high enough to create health risks except locally, where the presence of *E. coli* bacteria indicates unsafe levels for direct use of such water in irrigation and fisheries [90]. The high dilution factor and the high self-assimilation capacity of the Nile water make the pollution of the Nile River worrisome near cities and industrial discharges. The rapid increase of population and increase economic activities impose a heavy burden on the viability of the Nile water quality. Therefore, the pollution to Nile is a pressing national issue in Egypt [91]. In Egypt, water quality varies between poor and good in Middle Egypt and along Damietta branch. Due to accumulated industrial discharges into the river, very poor water quality is observed at the Rosetta branch. These discharges originate from industrial wastes of pesticides and fertilizers located at Kafr El-Zayat City and some factories located in Greater Cairo; this is besides agricultural discharges from the agricultural drainages in Beni Suef [92].

11 Water Quality Assessment

Water quality is an important issue since the Nile is the main source of drinking water in many countries especially in Egypt. The monitoring of the water characteristics and the description of the water conditions is the basis for the water quality assessment. Important aspects of an assessment are the interpretation and reporting of the results of monitoring and the making of recommendations for future actions. Thus, the sequence of water quality assessment consists of three components: monitoring, assessment, and management. In addition, the management process requires monitoring and assessments at periodic intervals for the effectiveness of management decisions. The principal objective of the global freshwater quality monitoring project provides an illustrative example of the complexity of the assessment task and its relation to management [90].

Different analytical methods were constructed to monitor the water quality status in freshwater ecosystems. The global freshwater monitoring project GEMS/WATER is based on a practical guidebook such as the GEMS/WATER Operational Guide [93, 94]. This book guide contains the necessary information for sampling selection and analysis and all information on quality control. Some recognized international methods were approved for water analysis such as the American Public Health Association [95], the German standard methods (Deutsche Einheitsverfahren zur Wasser-, Abwasser und Schlammuntersuchung (DIN)), and those of the USSR State Committee for Hydrometeorology and Environmental Control [96, 97] which are now used in Russia and other CIS countries.

Other important publications issued by UNESCO [98] provide methodology for water quality data collection, interpretation, and presentation.

12 Conclusions and Recommendation

The Nile River is one of the most important rivers in the world. Wastes that people dispose of can pollute the water of the Nile River affecting its quality and ecosystem. The main causes of water pollution are varied and include industrial wastes, sewage, and runoff from farmland, cities, and factory effluents. It is also worth mentioning that eutrophication of the water caused by organic and inorganic pollutants causes the overgrowth of some algae that secrete toxins which affect water quality and especially drinking water from Nile, which is considered the main source of drinking in many countries. Some specific algae cause odor, smell, or taste problems. The possible risks of fish cages on the water quality of the Nile River and its branches should also be considered, and the regulations and control by the governments should be implemented strictly to regulate such cages.

Nowadays, there is a great challenge of how to improve water quality and protection of the Nile River water in spite of pollution risks, particularly in developing African countries. There should be a regular and continuous monitoring scheme for developing ecosystems of the Nile River system. Environmental law should be developed and enforced to prohibit the discharge of wastewater such as agricultural, domestic, industrial, or other sources to the Nile River system. Also, cooperation in scientific and environmental monitoring of water quality and sources of pollution in African countries should be implemented since any pollution in any country of the Nile basin will affect the other countries. This book with the current chapter is one of many steps that should be taken to shed light on the issues of water quality and its effect on the ecosystem of the Nile River.

References

1. https://www.mtholyoke.edu/~emwether/worldpolitics/images/nile-basin-map.gif
2. Zaghloul S, Elwan H (2011) Water quality deterioration of middle Nile delta due to urbanization expansion, Egypt. In: 15th international water technology conference, Alex., Egypt
3. Chapman D, Chapman DE (eds) (1996) Water quality assessments. A guide to the use of Biota, sediments and water in environmental monitoring, 2nd edn. Chapman and Hall, London
4. Mapfumo E, Willms W, Chanasyk D (2002) Water quality of surface runoff from grazed fescue grassland watershed in Alberta. Water Q Res J Canada 37(3):543–562
5. Ezzat SM, Mahdy HM, Abo-State MA (2012) Water quality assessment of River Nile at Rosetta branch: impact of drains discharge. Middle East J Sci Res 12(4):413–423
6. Radwan M (2005) Evaluation of different water quality parameters for the Nile river and the different drains. In: Ninth international water technology conference, IWTC9 Sharm El-Sheikh, Egypt, pp 1293–1303
7. Canadian Council of Ministers of the Environment (CCME) (2001) Canadian water quality guidelines for the protection of aquatic life: CCME Water Quality Index 1.0, Technical Report. In: Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment, Winnipeg
8. Smith RL (1990) Ecology and field biology, 4th edn. Harper Collins, New York
9. Murdoch T (ed) (1991) Streamkeeper's field guide: watershed inventory and stream monitoring methods. Adopt-a-Stream Foundation, Lewiston
10. Greenberg AE (ed) (1995) Standard methods for the examination of water and wastewater, 19th edn
11. Edberg SC, Rice EW, Karlin RJ, Allen MJ (2000) *Escherichia coli*: the best biological drinking water indicator for public health protection. J Appl Microbiol Symp Suppl 88:106S–116S
12. Ali EM, Shabaan-Dessouki SA, Soliman AR, El Shenawy AS (2014) Characterization of chemical water quality in the Nile River, Egypt. Int J Pure Appl Biosci 2(3):35–53
13. Omer AAM (2003) Variability and speciation of heavy metals in surficial sediments from the River Nile, Egypt: assessment of the anthropogenic impact. In: Third international conference on geology of Africa, Assiut-Egypt, 7–9 December 2003, pp 1–19
14. Sallam AA, Ibrahim MS, Nasr IN (2006) Monitoring of organochlorine and organophosphorous residue in sediments of River Nile, Egypt. J Agric Sci Mansoura Univ 31(4):2451–2469
15. Zidan ZH, Gupta G, Abdel-Megeed MI, Mohamed KA, Bayoumi AE (2001) Monitoring of pesticide residues and metals water and soil system in industrial and agricultural areas at Kalubia Governorate, Egypt. In: The first conference of the central agriculture, Pesticide Laboratory, pp 119–138
16. Abbassy MS, Ibrahim HZ, Abdel-Kader HM (2003) Persistent organochlorine pollutants in the aquatic ecosystem of Lake Manzullo. Egypt Bull Environ Contam Toxicol 70:1158–1164
17. El-Tras WF, El-Kady NN, Tayel AA (2011) Infants exposure to aflatoxin M1 as a novel foodborne zoonoses. Food Chem Toxicol 49:2816–2819
18. Wahaab RI, Badawy MI (2004) Water quality assessment of the river Nile system: an overview. Biomed Environ Sci 17:87–100
19. Harris J, Abdel Nasser G (1995) Assessment of water quality in Egypt. National Water Quality Conservation Unit, PRIDE
20. EEAA (1994) Industrial wastewater pollution abatement in Kafr El-Zayat, Pre-Feasibility Study, Technical Cooperation Office for the Environment
21. Drainage Research Institute (1995) Reuse of drainage water in the Nile delta, monitoring, modeling and analysis. Final Report. NWRC, DRI, Cairo
22. Osman AG, Kloas W (2010) Water quality and heavy metal monitoring in water, sediments, and tissues of the African Catfish *Clarias gariepinus* (Burchell, 1822) from the River Nile. Egypt J Environ Protect 1:389–400

23. Tayel S, Yacoub AM, Mahmoud S (2008) Histopathological and haematological responses to freshwater pollution in the Nile Catfish *Clarias Gariepinus*. J Egpyt Acad Soc Environ Develop 9:43–60
24. Hayton BM (1990) Rate-limiting barriers to xenobiotic uptake by the gill. Environ Toxicol Chem 9:151–157
25. Ikem A, Egiebor N, Nyavor K (1990) Trace elements in water, fish and sediments from Tuskegee Lake, Southeastern USA. Water Air Soil Pollut 149:51–75
26. Gaber HS, El-Kasheif MA, Ibrahim SA, Authman MN (2013) Effect of water pollution in El-Rahawy drainage canal on hematology and organs of freshwater fish. World Appl Sci J 21 (3):329–341
27. Anwar WA (2003) Environmental health in Egypt. Int J Hygiene Environ Health 206:339–350
28. Mohamed M, Osman M, Potter T, Levin R (1998) Lead and Cadmium in Nile River water and finished drinking water in greater Cairo, Egypt. Environ Int 24:767–772
29. Amer AS, AbdelGawad HA (2012) Rapid bio-indicators assessment of macrobiotic pollution on aquatic environment. Int Water Technol J 2(3):196–206
30. El Bouraie MM, El Barbary AA, Yehia MM, Eman A, Motawea EA (2010) Heavy metal concentrations in surface river water and bed sediments at Nile Delta in Egypt. Suo 61(1):1–12
31. Abdel-Aal SHT, Shahin RR, Abdel-Hamid MA, Abdeltawa MM (1988) Impact of liquid wastes of industrial complex at Helwan on water quality of both Nile and canal streams. Egypt J Soil Sci 28:421–432
32. Bakhiet HHA (2015) Determination of heavy metals in fish tissues and water from White Nile Khartoum City – Sudan. J Environ Protect Sustainable Dev 1(3):178–181
33. Abu-Zeid MA (1991) Egypt's water resource management and policies, pp 5–45
34. El-Moutassem M (1994) Water problems in Egypt, p 34
35. Ewida AY (2014) Oil spills: impact on water quality and microbial community on the Nile River, Egypt. Int J Environ 3(4):192–198
36. El-Sayed M, Ouf EA (2009) Studies on river Nile aquatic environment II. Organic pollutants. Am Eurasian J Agric Environ Sci 5(2):159–170
37. Loganathan BG, Kannan K (1994) Global organochlorine contamination trends: an overview. Ambio 23:187–191
38. GESAMP (1989) The atmospheric input of trace species to the world ocean. GESAMP, Reports and studies, No. 38
39. Dunne T, Leopold LB (1978) Water in environmental planning. W.H. Freeman and Company, New York
40. El-Gendy KS, Abd-Allah AM, Ali HA, Tantawy GA, El-Sebae E (1991) Residue levels of chlorinated hydrocarbons in water and sediment samples from Nile Branches in the Delta, Egypt. J Environ Sci Health 26:15–36
41. El-Kabbany S, Rashed MM, Zayed MA (2000) Monitoring of the pesticide levels in some water supplies and agricultural land, in El-Haram, Giza (A.R.E.). J Hazard Mater 72:11–21
42. Malhat F, Nasr I (2013) Monitoring of organophosphorous pesticides residues in water from the Nile River Tributaries, Egypt. Am J Water Resour 1:1–4
43. Reynolds CS (1992) Eutrophication and the management of planktonic algae: what Vollenweider couldn't tell us. In: Sutcliffe DW, Jones JG (eds) Eutrophication: research and application to water supply. Freshwater Biological Association, Ambleside, pp 4–29
44. Vasconcelos VM (2001) Toxic freshwater cyanobacteria and their toxins in Portugal. In: Chorus I (ed) Cyanotoxins-occurrence, effects, controlling factors. Springer, Berlin, pp 64–69
45. Howarth RW (2008) Coastal nitrogen pollution: a review of sources and trends globally and regionally. Harmful Algae 8:14–20
46. Sigworth EA (1961) The production of palatable water. Taste Odor Control J 27(10):1–8 and 27(ll):l–4
47. Palmer CN (1962) Algae in water supplies. U.S. Public Health Service Publication No. 657, - Washington, DC, 88 p. In: Lin SD (1977) Taste and odors in water supplies; A review, Illinois state water survey, Urbana, USA

48. Silvey JG, Henley DE, Wyatt JT (1972) Planktonic blue-green algae: growth and odor-production studies. J Am Water Works Assoc 64(l):35–39
49. Safferman RS, Rosen AA, Mashni CI, Morris ME (1967) Earthy-smelling substance from a blue-green alga. Environ Sci Technol 1(5):429–430
50. Gerber NN, Lechevalier HA (1965) Geosmin, and earthy-smelling substances isolated from actinomycetes. Appl Microbiol 13(6):935–938
51. Dzialowski AR, Smith VH, Huggins DG, Denoyelles F, Lim NC, Baker DS, Beury JH (2009) Development of predictive models for geosmin-related taste and odor in Kansas, USA, drinking water reservoirs. Water Res 43(11):2829–2840
52. Omar WMW (2010) Perspectives on the use of algae as biological indicators for monitoring and protecting aquatic environments, with special reference to Malaysian freshwater ecosystems. Trop Life Sci Res 21(2):51–67
53. Stevenson RJ, Pan Y (1999) Assessing ecological conditions in rivers and streams with diatoms. In: Stoemer EF, Smol JP (eds) The diatom: applications to the environmental and earth science. Cambridge University Press, Cambridge, pp 11–40
54. Whitehead PG, Hornberger GM (1984) Modelling algal behaviour in the River Thames. Water Res 18(8):945–953
55. Cosgrovea JDW, Morrison P, Hillman K (2004) Periphyton indicate effects of wastewater discharge in the near-coastal zone, Perth, Western Australia. Estuar Coast Shelf Sci 61 (2):331–338
56. Hill MO, Mountford JO, Roy DB, Bunce RGH (1999) Ellenberg's indicator values for British plants, vol 2. Institute for Terrestrial Ecology. ECOFACT, Technical Annex, Huntingdon
57. Hill BH, Herlihy AT, Kaufmann PR, Stevenson RJ, McCormick FH, Jonhson CB (2000) Use of periphyton assemblage data in an index of biotic integrity. J North Am Bethol Soc 19 (1):50–67
58. Ho SC, Peng TS (1997) The use of river plankton and fish in water quality classification of Sg. Perai, Sg. Juru and Sg. Perlis. J Ensearch 10(2):115–124
59. Joubert G (1980) A bioassay application for quantitative toxicity management using the green algae, *Selenastrum capricornutum*. Water Res 14:1759–1763
60. Dwivedi BK, Pandey GC (2002) Physicochemical factors and algal diversity of two ponds (Girija Kund and Maqubara Pond), Faizabad, India. Poll Res 21(3):361–369
61. Jafari NG, Gunale VR (2006) Hydrobiological study of algae of an urban freshwater River. J Appl Sci Environ Manag 10:153–158
62. Jafari N (2009) Using algae to assess environmental conditions in river. Int J Algae 11:246–259
63. Mohamed ZA (2011) Cyanotoxins in Egypt and Saudi Arabia. In: Nriagu JO (ed) Encyclopedia of environmental health. Elsevier, Burlington, pp 872–880
64. Mohamed ZA, Carmichael WW (2000) Seasonal variation in microcystin levels of River Nile water at Sohag city, Egypt. Ann Limnol 36:227–234
65. Mohamed ZA, El-Sharouny HA, Ali WS (2007) Microcystin concentrations in the Nile River sediments and removal of microcystin-LR by sediments during Batch experiments. Arch Environ Contam Toxicol 52:489–495
66. Amer R, Diez B, El-Shehawy R (2009) Diversity of hepatotoxic cyanobacteria in the Nile Delta, Egypt. J Environ Monit 11:126–133
67. Haider S, Naithani V, Viswanathan PN, Kakkar P (2003) Cyanobacterial toxins: a growing environmental concern. Chemosphere 52:1–21
68. Carmichael WW (1997) The cyanotoxins. Adv Bot Res 27:122–256
69. Carmichael WW (2000) A mini-review of cyanotoxins; Toxins of cyanobacteria (blue-green algae). In: Proceedings of the Xth international IUPAC symposium on mycotoxins and phycotoxins, Guaruja (Brazil), 21–25 May 2000
70. Mohamed ZA, El-Sharouny HA, Ali WS (2006) Microcystin production in benthic mats of cyanobacteria in the Nile River and irrigation canals, Egypt. Toxicon 47:584–590

71. Verschuren D, Johnson TC, Kling HJ, Edgington DN, Leavitt PR, Brown ET, Talbot MR, Hecky RE (2002) History and timing of human impact on lake Victoria, East Africa. Proc R Soc Lond B 269:289–294
72. Gugger M, Lenoir S, Berger C, Ledreux A, Druart JC, Humbert JF, Guette C, Bernard C (2005) First report in a river in France of the benthic cyanobacterium *Phormidium favosum* producing anatoxin-a associated with dog neurotoxicosis. Toxicon 45:919–928
73. Mohamed ZA, Deyab MA, Abou-Dobara MI, El-Sayed AK, El-Raghi WM (2015) Occurrence of cyanobacteria and microcystin toxins in raw and treated waters of the Nile River, Egypt: implication for water treatment and human health. Environ Sci Pollut Res 22:11716–11727
74. Dittmann E, Wiegand C (2006) Cyanobacterial toxins-occurrence, biosynthesis and impact on human affairs. Mol Nutr Food Res 50:7–11
75. Codd GA, Morrison LF, Metcalf JS (2005) Cyanobacterial toxins: risk management for health protection. Toxicol Appl Pharmacol 203:264–272
76. Reynolds GS (1988) Functional morphology and the adaptive strategies of freshwater phytoplankton. In: Sandgren CD (ed) Growth and survival strategies of the freshwater phytoplankton. Cambridge University Press, Cambridge, pp 388–433
77. Sivonsen K (1990) Effect of light, temperature, nitrate, orthophosphate and bacteria on growth and hepatotoxin production by *Oscillatoria agardhii* strain. Appl Environ Microbiol 56:2658–2666
78. Mohamed ZA (1998) Studies on the Egyptian toxic freshwater cyanobacteria (blue-green algae): identification, production and removal of microcystins. PhD thesis, South Valley University, Egypt, p 182
79. Lehman SY, Sandgren CD (1985) Species-specific rates of the growth and grazing loss among freshwater algae. Limnol Oceanogr 30:34–46
80. EPA (Environmental Protection Agency) (2012) Cyanobacteria and cyanotoxins: information for drinking water systems. Office of Water 4304T. EPA-810F11001, p 9
81. Degefu F, Mengistu S, Schagerl M (2011) Influence of fish cage farming on water quality and plankton in fish ponds: a case study in the Rift Valley and North Shoa reservoirs, Ethiopia. Aquaculture 316:129–135
82. Ali M, Abdel-Meguid M, Abdin A (2006) Assessment of floating fish cages impacts on the water, fauna, flora, sediments, aquatic weeds, fish and hydraulics of Damieta branch, Scientific Bulletin, Faculty of Engineering, Helwan University
83. El-Kholy R (2012) Assessment of fish cages' impacts on the water quality in Rosetta branch of the Nile River using remote sensing technology. Nile Basin Water Sci Eng J 5:79–89
84. Beveridge MCM (1985) Cage and pen fish farming. Carrying capacity models and environmental impact. FAO Fish Tech Paper 255:131
85. FAO (2005) Aquaculture production, 2003, year book of fishery statistics, vol 96/2. Food and Agriculture Organization of the United Nations, Rome, Italy
86. El-Sheekh MM (2009) River Nile pollutants and their effect on life forms and water quality. In: Dumont HJ (ed) The Nile: origin, environments, limnology and human use. Springer Science
87. Nixon SW (2003) Replacing the Nile: are anthropogenic nutrients providing the fertility once brought to the Mediterranean by a great River? AMBIO J Hum Environ 32(1):30–39
88. El-Gohary F, Abdel Wahaab R (1992) Lake Manzala water quality, impact assessment of sources of pollution. UNEP/WB-Lake Manzala, Cairo
89. Ogutu-Ohwayo R, Hecky RE, Cohen AS, Kaufman L (1997) Human impacts on the African Great Lakes. Environ Biol Fish 50:117–131
90. APRP-Water Policy Activity Contract PCE-I-00-96-00002-00 Task order 22 (2002) Survey of Nile System Pollution Sources. Rep. No. 64: 84 pp
91. El-Ayouti A, Abou-Ali H (2013) Spatial heterogeneity of the Nile water quality in Egypt. J Environ Stat 4(8):1–12
92. CEMSWE (2008) The annual report of the results of the national network for monitoring the water pollutants of the Nile River and its branches in 2008. Technical report, Central

Department of Environmental A_airs - Center of Environmental Monitoring and Studies of the Working Environment (CEMSWE) - Ministry of Health, Egypt
93. WHO (1991) GEMS/WATER 1990–2000. The Challenge Ahead. WHO/PEP/91.2. World Health Organization, Geneva
94. WHO (1992) GEMS/WATER operational guide, 3rd edn. World Health Organization, Geneva
95. APHA (1989) Standard methods for the examination of water and wastewater, vol 1, 17th edn. American Public Health Association, Washington, p 268
96. USSR State Committee for Hydrometeorology and Environmental Control (1987) Methods for bioindication and biotesting in the natural waters, vol 1. Hydrochemical Institute, Leningrad, 152 pp
97. USSR State Committee for Hydrometeorology and Environmental Control (1989) Methods for bioindication and biotesting in the natural waters, vol 2. Hydrochemical Institute, Leningrad, 275 pp
98. UNESCO (1983) International legend for hydrogeological maps. Technical Documents in Hydrology, SC.841/S7. United Nations Educational Scientific and Cultural Organization, Paris, 51 pp

Fish and Fisheries in the Nile Basin

Abdel-Fattah M. El-Sayed

Abstract Fish landing from inland fisheries in the Nile Basin countries represent a major component of total fisheries production. In 2013, inland fish production in these countries reached 1,503,429 tonnes, representing 70–100% of total fisheries production. Types of fisheries, fishing gear and methods are described in this chapter. Aquaculture in Nile Basin countries, except in Egypt, Uganda and Kenya, is still in the infancy stage. In 2013, aquaculture production in the Nile Basin reached 1,228,352 tonnes. Over 89% of this production comes from a single country: Egypt followed by Uganda (8%).

More than 800 fish species have been estimated in the Nile Basin, wetlands and rivers; 128 of them belonging to 27 families inhabit the River Nile. The majority of these species belong to families Cichlidae, Cyprinidae, Mormyridae and Mochokidae. Cichlid species dominate the fish fauna of Nile Basin lakes and rivers. The fish fauna in Lake Tana is dominated by the cyprinid genera *Barbus* and *Labeobarbus*. Nile perch *Lates niloticus* and Nile tilapia *Oreochromis niloticus* were introduced into Lake Victoria, the largest freshwater lake in Africa, in the 1950s and 1960s. The predation by Nile perch, excessive fishing and habitat deterioration caused a decline in many endemic cichlid (haplochromine) and non-cichlid species, while Nile perch and Nile tilapia stocks increased. As a result, the multispecies fishery of Lake Victoria has shrunk and is limited to Nile perch, Nile tilapia and sardine-like cyprinid dagaa (*Rastrineobola argentea*). Lake Victoria is the main source of fish stocks for Lake Kyoga. Therefore, most of the endemic fishes of Lake Kyoga are conspecific with those of Lake Victoria. About 48 species belonging to 14 families occur in Lake Albert. Endemic species are represented by one endemic cyprinid, one centropomid and four haplochromine cichlid species. The lake shares the families Polypteridae, Citharinidae, Malapteruridae and

A.-F.M. El-Sayed (✉)
Oceanography Department, Faculty of Science, Alexandria University, Alexandria, Egypt
e-mail: afmelsayed@gmail.com

A.M. Negm (ed.), *The Nile River*,
Hdb Env Chem (2017) 56: 387–412, DOI 10.1007/698_2016_98,

Centropomidae with the River Nile. Lake Albert also has relatively high numbers of species belonging to the families Alestiidae and Bagridae. Over 78 fish species, belonging to 8 families, have been recorded in lakes Edward and George. These fish fauna are dominated by the family Cichlidae with more than 60 species. Other fish groups include lungfish and African catfish. In Lake Nasser, 56 species belonging to 17 families have been reported.

The major challenges and threats facing fisheries resources in the Nile Basin are species introductions; degradation of aquatic habitats and biodiversity; unsustainable fishing practices; and pollution and eutrophication resulting from human populations and invasive weeds. Management plans and necessary measures have been suggested.

Keywords Aquaculture, Fish, Fisheries, Fisheries management, Nile Basin

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1 Introduction

The Nile Basin extends from 4°S to 31°N and covers about 3.1 million km^2 (about 10% of the African land), which includes 81,500 km^2 of lakes and 70,000 km^2 of swamps and wetlands. The basin includes 11 countries (Burundi, the Democratic

Republic of the Congo, Egypt, Eritrea, Ethiopia, Kenya, Rwanda, Sudan, South Sudan, Tanzania and Uganda) (the map is available at: https://www.mtholyoke.edu/~emwether/worldpolitics/images/nile-basin-map.gif). It is inhabited by about 173 million people (20% of the African population, or 57% of the entire population of these countries). The majority of these populations depend mainly on land crops and animal production for their livelihoods [1, 2]. The irrigated area of the basin is estimated at approximately 7.6 million ha, with the potential of increasing to 10.2 million ha [3].

The River Nile is the longest river in the world. It flows from the Ruvyironza River, which is its most remote headstream in Burundi, northward of the Mediterranean Sea by a distance of 6,671 km [4]. The River passes through different climatic zones and is fed from different water sources, creating huge wetlands throughout the whole basin. Seventeen river basins feed into Lake Victoria, with the greatest contribution from the Kagera River [5]. The upper branches of the Kagera River in Rwanda are the main source of the Nile water. The Kagera River runs through the boundary of Rwanda northward and continues along the border of Tanzania before draining into Lake Kyoga between Lake Victoria and Lake Albert [6].

The section between Lake Victoria and Lake Albert is known as the Victorian Nile. The part of the Nile extending from the northern end of Lake Albert and flowing through northern Uganda to the South Sudan border is called Albert Nile, where in South Sudan it becomes the Bahr El-Jebel. It runs through the Sudd wetlands and then is called the White Nile at its conjunction with Bahr Al-Ghazal. At Omdurman (Khartoum, Sudan), the White Nile merges with the Blue Nile (which is 1,529 km long and gets its water from Lake Tana in the Ethiopian Highlands), where the name becomes Nile or Main Nile. Further downstream, the Nile flows north to join with the Atbara River and then it traverses the Nubian Desert. The Nile flows north towards the Mediterranean Sea through the Nile Delta which splits into the two main Nile delta branches, the Rasheed (Rosetta) and Domiat (Damietta) branches.

2 Fish Production in the Nile Basin

2.1 Capture Fisheries

Fish landing from inland fisheries in the Nile Basin countries represents a major component of total fisheries production (Fig. 1). In 2013, inland fish production in these countries reached 1,503,429 tonnes, representing 70–100% of total fisheries production. Moreover, 100% of fisheries production in Burundi, Ethiopia, Eritrea, Rwanda, South Sudan and Uganda came from inland fisheries, because these countries, except Eritrea, are inland countries, without any marine borders. In

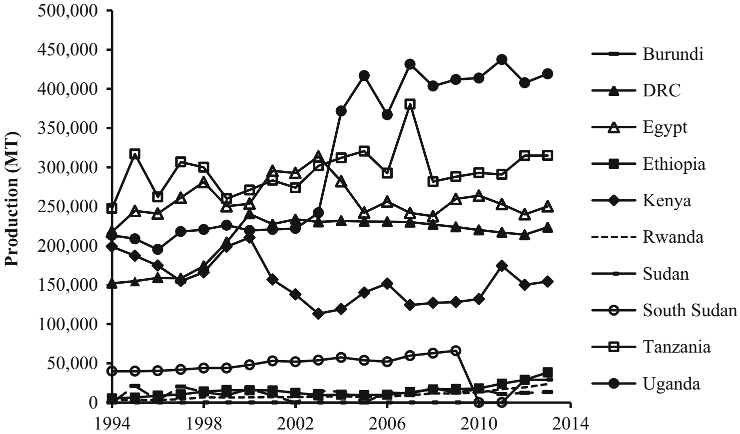


Fig. 1 Production of inland fisheries in Nile Basin countries during 1994–2013. Source: FAO [7]

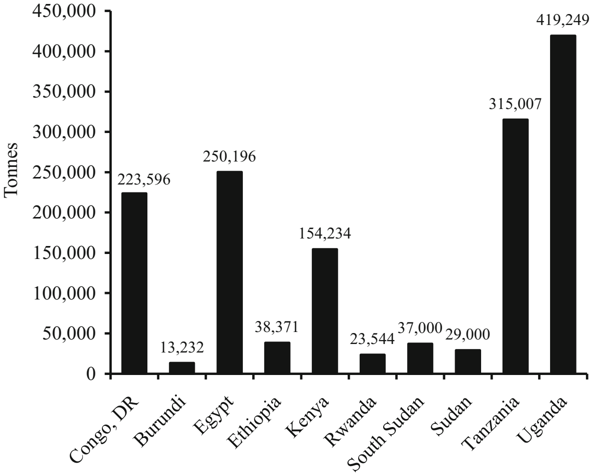
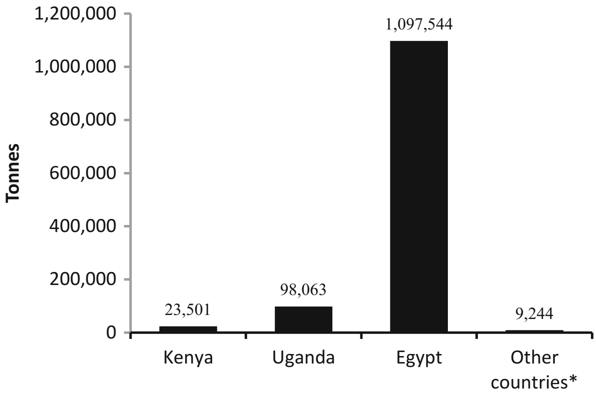


Fig. 2 Inland fish production from natural fisheries in Nile Basin countries in 2013. Source: FAO [7]

Egypt, DRC, Kenya, Sudan and Tanzania, inland fish production represents 70, 98.3, 94.4, 85.3 and 82.4% of total capture fisheries, respectively.

Uganda, Tanzania, DRC, Egypt and Kenya contributed 91% to total inland fisheries in the Nile Basin in 2013 (Fig. 2). Moreover, Uganda and Tanzania alone landed 49% of total yield. Inland fish production in Burundi, Ethiopia, Eretria, Rwanda, Sudan and South Sudan was insignificant.

Fig. 3 Aquaculture production in the Nile Basin countries in 2013. Source: FAO [7]. *Other countries include DRC, Burundi, Ethiopia, Rwanda, South Sudan, Sudan and Tanzania



2.2 *Aquaculture*

Aquaculture is the farming of aquatic organisms, including fish, molluscs, crustaceans and aquatic plants in freshwater, brackish water or the marine environments. Aquaculture in sub-Saharan Africa dates back to the 1920s, when trout breeding was introduced into Kenya and Madagascar and later into Tanzania. However, in spite of this long history, aquaculture still remains marginalized, with limited contribution to national economies.

Therefore, aquaculture in Nile Basin countries, except in Egypt, Uganda and Kenya, is still in its infancy stage and even does not exist in some countries (Eritrea). In 2013, aquaculture production in the Nile Basin reached 1,228,352 tonnes. Over 89% of this production comes from a single country, Egypt, followed by Uganda (8%) (Fig. 3). Aquaculture development in Egypt will be described in details in Chap. 18. In Uganda, the government adopted ambitious aquaculture development strategies to boost livelihoods and food security, particularly in urban areas, with emphasis on the northern and eastern areas of the country (see www.thefishsite.com).

3 Fish and Fisheries in Nile Basin Lakes, Wetlands and Rivers

The Nile Basin is characterized by vast areas of lakes, permanent wetlands and seasonal flooding wetlands, covering about 10% of the basin. These wetlands include five major natural lakes (Victoria, Edward, Albert, Kyoga and Tana), with a surface area of more than 100,000 km^2. The permanent wetlands and seasonal flooding include the Sudd, Bahr Al-Ghazal and Machar marshes. Five major reservoir dams (Aswan High Dam (Lake Nasser-Nubia), Roseires, Khashm El-Girba, Sennar and Jebel Aulia) are also found in the basin [6].

Table 1 Number of fish species estimated in the Nile Basin

Basin	River Nile	Lakes Victoria and Kyoga	Lakes Edward and George	Lake Albert	Lake Tana	Sudd	Lake Nubia	Lake Nasser
Total families	27	12 (+1)	8	14	4	21	10	17
Total species	128	600–700	78	48	27	68	25	56

Modified from: Ali [8], Witte et al. [9] and van Zwieten et al. [10]

More than 800 fish species have been estimated in the Nile Basin, wetlands and rivers (Table 1); 128 of them, belonging to 27 families, inhabit the River Nile [9]. The families Cichlidae, Cyprinidae, Mormyridae, Mochokidae, Alestiidae and Bagridae comprise the vast majority of these species.

The following sections shed the lights on these water sources, with emphasis on their fish and fisheries.

3.1 Lake Victoria

Lake Victoria is the largest freshwater lake in Africa, and the second largest in the world, only after Lake Superior in North America. It has a surface area of 68,800 km^2 with a mean depth of 40 m and maximum depth of 80 m. The lake lies across the equator and has a shoreline of 3,450 km with a catchment area of 193,000 km^2 (Uganda 30,880 km^2, 16%; Kenya 42,460 km^2, 22%; Tanzania 84,920 km^2, 44%; Rwanda 21,120 km^2, 11%; Burundi 13,510 km^2, 11%) [11, 12]. The lake water is shared by three countries: Tanzania (51%), Uganda (43%) and Kenya (6%) (Fig. 4).

Lake Victoria is the most productive freshwater lake in the world, with annual fish yields of 800,000 tonnes, an export industry worth US$250 million [13]. The Lake Victoria fisheries subsector provides employment to over 3 million people of whom about 200,000 are fishermen [14].

Historically, Lake Victoria has been a multispecies fishery of over 500 endemic fish species with cichlid haplochromines and tilapiines being the most dominant species. In fact, haplochromines comprised 83% of the artisanal catches in the 1970s, whereas tilapiines (i.e. the *Oreochromis esculentus* and *O. variabilis*) were the base of commercial fishery. Other important fisheries included bagrid fishes (*Bagrus* spp.), catfish (*Clarias* spp.), *Synodontis* spp., *Chile* spp., *Protopterus* spp. and *Labeo* spp.

Nile perch, *Lates niloticus*, was unofficially introduced into Ugandan waters of the lake in 1954 [15], while Nile tilapia, *Oreochromis niloticus*, was introduced in the 1960s. After the introductions of the Nile perch and Nile tilapia, fish landing increased fivefold in the late 1980s, with Nile perch contributing about 60%. About 200 endemic haplochromine species have become almost extinct due to predation

Fig. 4 Major Nile Basin lakes (http://www.grid.unep.ch/activities/sustainable/nile/)

by the Nile perch [16], while Nile tilapia bloomed. The eradication of the haplochromines which constituted different trophic groups resulted in unutilized niches in the system, leading to substantial changes in the lake productivity and increase of detritus material and zooplankton. These phenomena resulted in the bloom of some filter feeders such as *Caridina niloticus* and *Rastrineobola argentea*. These changes were associated with excessive fishing pressure, predation and competition among the species. As a result, the multispecies fishery of Lake Victoria has been gradually shrinking and limited to the current three species fishery (Nile perch, dagaa and Nile tilapia) (Fig. 5).

Nile perch is the basis of the export industry, supporting about 30 fish processing factories in the three countries: Tanzania, Uganda and Kenya. About 75% of the Nile perch landed here is exported, mainly to Europe, the USA and the Middle East, contributing significantly to employment, income, GDP and foreign exchange [11].

Dagaa, which is a native sardine-like cyprinid (*Rastrineobola argentea*) (also known as mukene and omena) has become the second most important commercial species in Lake Victoria, since the decline in Nile perch fisheries. These fish are an important protein source for the poor, as it is cheap and highly nutritious. Most of these fish are dried and sold either for domestic human consumption or for animal

Fig. 5 Dagaa (*Rastrineobola argentea*) (*left*), Nile perch (*Lates niloticus*) (*top right*) and Nile tilapia (*Oreochromis niloticus*) (*bottom right*) are the most important fishes in Lake Victoria. Dagaa and Nile tilapia photos were provided by A.-F. M. El-Sayed, while the Nile perch photo was provided by A. Halls

feed. Much is also exported within the region, particularly the Democratic Republic of the Congo and Southern Africa.

Lake Victoria witnessed considerable environmental changes during the past decades. As a result, several responsive ecological adaptations were observed. For example, reproductive strategies of several species including cichlids Nile tilapia, *Oreochromis niloticus*, changed [17] haplochromine cichlids, and the cyprinid, *Rastrineobola argentea*, [18] also changed. There have also been dietary shifts in zooplanktivorous and detritivorous haplochromines [19, 20], in *Rastrineobola argentea* [21], in *Oreochromis niloticus* [22], in the catfishes *Bagrus docmak* and *Schilbe intermedius* [23] and the alestiid *Brycinus sadleri* [24]. The amounts of macro-invertebrates in the diets of species increased significantly. Morphological adaptations were also observed in both the cyprinid *R. argentea* and the haplochromines to the increased hypoxic conditions, the decreased water transparency and the changes in diet composition [20, 25, 26].

3.1.1 Fishing Methods and Effort

There are different types of fishing gear used in Lake Victoria. Gillnets, longlines and traps are used for large fish species, while beach seines and small seine nets are used for dagaa fishery. Cast nets and handlines are also commonly used. However, gillnets are the most common fishing gear for commercial fishery. About 71% of fishing boats operate gillnets, while 23% use dagaa seine nets, 5% long lines and 1% traditional traps [11, 27].

Fishing efforts in Lake Victoria have been increasing dramatically over the years by partner states riparian to the lake (Kenya, Tanzania and Uganda). Between 2000 and 2012, the number of fishers increased by 59% from 129,305 to 205,249 [11]. Similarly, the total number of fishing crafts (including foot fishers and rafts) increased from 42,519 to 71,138 during the same period, an increase of 67%. Motorized fishing crafts (outboard engines) increased by almost fourfold, from 4,108 in 2000 to 20,217 in 2012. The total number of gillnets also increased by 59%, from 650,653 in 2000 to 1,032,984 in 2012 and longline hooks by 280% from 3,496,247 to 13,257,248 hooks. Fisheries supporting facilities and infrastructures have also increased and developed. These include fish stores, net repair facilities, weather roads, electricity supply, smoking kilns, drying racks and shops selling fishing gears [11].

As a result of the increase of fishing effort, fish landing increased from 620,000 tonnes in 2000 to 1,061,107.6 tonnes in 2006, but with changes in the catch composition. For example, the production of Nile perch decreased from about 60% of the total catch in the late 1980s to 24% in 2006 [11]. On the other hand, the catch of dagaa represented 40% of the total catch in 2000, but increased to 54% in 2006.

3.2 Lake Kyoga, Uganda

Lake Kyoga is located in central Uganda north of Lake Victoria, 914 m above sea level. It is a large shallow lake, with an average depth of about 3 m, while its maximum depth is 5.7 m. Lake Kyoga was formed by ponding back of the Kafu River. It lies in the flooded tributaries of the low west-flowing Kafu River. The lake has fingerlike extensions, including Lake Kwania, Lake Bisina and Lake Opeta, with a total surface of 1,720 km^2 and a catchment area of about 75,000 km^2. The lake receives the outflow from the Victoria Nile and is drained to Lake Albert (World Lakes Database: http://wldb.ilec.or.jp/data/databook_html/afr/afr-15.html). Lake Kyoga has three different environmental zones: the open water zone which is deeper than 3 m; the water less than 3 m deep, which is covered completely with macrophytes, especially water lilies and water hyacinth; and the swampy zone fringing the shoreline, which is covered mainly with papyrus.

It has been suggested that most of the endemic fishes of Lake Kyoga, particularly haplochromine cichlids, are conspecific with those of Lake Victoria [28, 29]. It is thus very likely that Lake Victoria was the chief source of fish stocks for Lake Kyoga. Therefore, 100 species of endemic haplochromines are found in Lake Kyoga. This similarity in species composition led some authors to treat the fish fauna of Lakes Victoria and Kyoga together [30] as mentioned in Table 2.

Table 2 Number of fish species in the River Nile and Nile Basin lakes

Family	River Nile	Lakes Victoria and Kyoga	Lakes Edward and George	Lake Albert	Lake Tana	Sudd	Lake Nubia	Lake Nasser
Protopteridae	2	1	1	1	–	1		1
Polypteridae	3			1		2		1
Anguillidae	1							
Clupeidae	1							
Osteoglossidae	1					1		
Notopteridae	1					1		
Mormyridae	15	7	2	7		8	4	7
Gymnarchidae	1					1		1
Kneriidae	1							
Alestiidae (Characidae)	8	2		5		5	3	6
Distichodontidae	7					5		1
Citharinidae	2			4		3	2	2
Cyprinidae	25	17	4	5	24	9	4	13
Balitoridae	1				1			
Bagridae	6	1	1	3		5	4	2
Schilbeidae	5	1		2		3	2	2
Amphiliidae	1							
Clariidae	7	6	4	2	1	2	1	2
Malapteruridae	1			1				1
Mochokidae	15	2		3		5	2	6
Cyprinodontidae	7	7	4	2		4		
Channidae	1					1		
Centropomidae	2	(1)[a]		2		1		
Eleotridae	1					1		
Cichlidae	10	600 (+4)[a]	60	10	1	7	2	4
Anabantidae	2	1	2			2		
Mastacembelidae	–	1						
Tetraodontidae	1					1		1
Latidae							1	1
Claroteidae								5
Total families	27	12 (+1)[a]	8	14	4	21	10	17
Total species	128	600–700	78	48	27	68	25	56

Modified from: Ali [8], Witte et al. [9] and van Zwieten et al. [10]
[a]Introduced species

The abundance of Cichlid *Haplochromis* and other small defenceless species in Lake Kyoga has been mainly due to the lack of large predatory fish. However, the introduction of the Nile Perch (*Lates niloticus*) into the lake in the late 1950s led to almost complete disappearance of many native fish species, such as *Synodontis* *victoriae*, *Engraulicypris argentus*, *Barbus kiogae*, *Tilapia esculenta*, *Tilapia variabilis*, *Mormyrus kannume*, *Clarias mossambicus*, *Schilbe mystus and Haplochromis macrodon*. Consequently, the Nile perch and another introduced tilapiine species, *Oreochromis niloticus*, currently form the bulk of the fisheries of Lake Kyoga [31].

3.3 Lake Tana (Ethiopia)

Lake Tana is the largest lake in Ethiopia, with a surface area of 3,050 km^2. It is located in the north-western Ethiopian highlands, 500 km north of the capital Addis Ababa, at an altitude of about 1,800 m above sea level (ASL). The lake is relatively shallow; with an average depth of 8 m, while the maximum depth is 14 m [6]. It is surrounded by seasonal floodplains, where permanent *Cyperus papyrus* wetlands fringe much of the lake, forming the largest lake-wetland region in Ethiopia. The fishery in Lake Tana is confined to the southern part of the lake around Bahir Dar Gulf [32], about 30 km downstream from the Blue Nile outflows, and is isolated from the lower Nile Basin by 40 m-high waterfalls [6].

In contrast to Lake Victoria, where cichlid haplochromines and tilapiines dominate, the fish fauna of Lake Tana is dominated by the cyprinid species. About 24 cyprinid species are found in the lake (18 of them are endemic) out of 44 cyprinids species reported in Ethiopian freshwater [9]. The following species groups are the major endemic commercial fishes in Lake Tana [33]:

1. Family *Cyprinidae*: the largest fish family in the lake. The following four genera are endemic: *Varicorhinus* (single species; *V. beso*), *Garra* (4 species; *Garra dembecha*, *G. microstoma* and *G. tana*), *Labeobarbus* spp. (represented by about 15 species; [6]) and *Barbus* (3 species; *Barbus humilis*, *B. pleurogramma* and *B. tanapelagicus*).
2. Family *Cichlidae*: represented by one fish species, Nile tilapia (*Oreochromis niloticus*).
3. Family *Clariidae*: represented by one fish species, African catfish or walking catfish (*Clarias gariepinus*).

Generally, cyprinid fishes lack oral jaw teeth, stomachs and cellulases. This may impose phylogenetic constraints on some trophic specializations. Therefore, Lake Tana lacks fishes with extreme specializations. However, cyprinids have developed and diversified pharyngeal jaws, enabling these fish to break down tough and strong food types [34]. Cyprinids are also characterized by a sensory and highly muscular palatal organ required for sorting food from the nonfood benthos. These features enable these cyprinid fishes to find their niches in the benthic zone in Lake Tana.

Traditionally, Lake Tana fishery is limited to the shore areas and consisted mainly of papyrus reed boats using traps and small gillnets. Up to 1985, fishing activity was linked to subsistence fishing in rivers and swampy areas mainly with hooks, cast nets and gillnets. In 1986, motorized fishing boats using gillnets, mainly for tilapia, large catfish and migrating large barbs during their spawning migration, were introduced to Lake Tana fisheries [35]. There are currently 400 reed boats and 25 motorized boats [36]. The reed boat fisheries account for about 40%, whereas the motorized fishery contributes about 60% to the catch. This switch negatively affected the fish stock in the lake, leading to a gradual decrease in fish landing. However, fishing efforts and catch have been increasing steadily during the past few years. The number of fishers increased from 514 in 1996 to 1,700 in 2010. Fish production increased from 1,109 tonnes to 6,561 tonnes during the same period [37].

The gillnets used in Lake Tana fisheries are either nylon monofilament gillnets (7–9 cm mesh size, 20 m long) or multifilament nets (8–12 cm mesh sizes, 100 m long). Typically, the motorized boat fishery uses the bigger multifilament gillnets. The reed boat fishery uses both monofilament and multifilament gillnets, depending mostly on supply. There is also a chase and trap fishery, which is confined to the southern part of the lake and practised mainly during the dry season at low water levels.

3.4 Lake Albert

Lake Albert is located in the western arm of the African Great Rift Valley, at an altitude of 618 m above sea level. The lake covers a surface area of 5,270 km^2, with a maximum depth of 58 m, shared between Uganda (60%) and the Democratic Republic of the Congo (40%). The waters of Lake Albert are fed by the Semliki River and Kafu River to the south and the Victoria Nile at the northern tip of the lake [38].

Six main fish habitats have been identified in Ugandan water of Lake Albert: (1) shallow river-associated waters, (2) open sandy shorelines, (3) lagoons, (4) large bays, (5) rocky escarpments and (6) open water habitats [39]. These habitats harbour 40 fish species belonging to 12 families and are considered natural refuges to fishes in the lake. Lagoons, large bays and rocky shores have higher numbers of fish species. The shoreline waters are inhabited mostly by juvenile fishes.

Lake Albert contains great fish diversity, with 48 species belonging to 14 families (Table 2) [28, 29]. However, endemic species are relatively limited, represented by one endemic cyprinid, one centropomid and four haplochromine cichlid species [29, 40]. The lake shares the families Polypteridae, Citharinidae, Malapteruridae and the Centropomidae with the River Nile. Lake Albert also has a relatively high number of species belonging to the families Alestiidae and Bagridae, while the number of cichlid species is only ten. Among these ten cichlid species, four are tilapiines (*Tilapia zillii*, *Sarotherodon galilaeus*, *Oreochromis niloticus* and *O. leucostictus*) [41] and the other six species are haplochromines [29].

However, commercial catches in Lake Albert waters are largely based on small pelagic species especially *Brycinus nurse* and *Neobola bredoi*, which represent

80% of the total landing [38]. The annual catch in Lake Albert has been estimated by the Uganda National Fisheries Resources Research Institute in 2007 at about 182,000 tonnes [42]. This catch was dominated by *Brycinus nurse*, which represented 64% of the total landing.

Nile perch, Nile tilapia, tigerfish, *Alestes baremoze*, bagrid fish (*Bagrus docmac*), lungfish and African catfish are also widely exploited. The lake fishery contributes more than 30% to total fish production in Uganda. An estimated 8,800 fishers with a fleet of about 2,500 small fishing boats operate within Ugandan waters of the lake.

As recorded in Lake Victoria, there has been a gradual shift in fisheries in Lakes Albert, Kyoga and Edward in Uganda from multispecies to a few species fisheries. This has been largely due to the introduction of the predator Nile perch (*Lates niloticus*) into lakes Albert and Kyoga and the introduction of Nile tilapia (*Oreochromis niloticus*) into waterbodies where they originally did not exist.

Gillnets, particularly drift gillnets, are a major fishing method used in Lake Albert. The target fish species for the gillnet fishery are Nile perch, tilapia species, *Bagrus*, *Clarias*, *Protopterus*, *Alestes*, *Hydrocynus* and many other demersal species. Angling gear (handlines) which can be operated as a trolling gear is also used for commercial fishery in Lakes Victoria, Kyoga and Albert. This method targets predacious species such as Nile Perch and alestiid fish (*Hydrocynus*). Longline gear is also used for fishing predator species like Nile perch, *Protopterus*, *Clarias*, *Bagrus*, etc. It comprises a long mainline (100–300 m), rigged with monofilament twine (diameter 1–2 mm) or multifilament twine (ply 36–60), and bears short snoods (0.3–0.8 m) carrying baited fishhooks.

3.5 Lakes Edward and George

Lakes Edward and George are separated from Lake Albert by falls in the Semliki River. Lake Edward is the smallest lake of the African Great Lakes. It is located in the western part of the East African Rift at an elevation of 920 m above sea level. The lake covers a surface area of 2,300 km^2, and a catchment area of 12,096 km^2, with a maximum depth of 117 m and a mean depth of 17 m. The lake is shared between the Democratic Republic of the Congo (DRC) (1,630 km^2 (71%)) and Uganda (670 km^2 (29%)). It receives the inflow of the Kazinga Channel which flows from Lake George to the north-west. It is also fed by a number of small rivers: the Nyamugasani River, the Ishasha River, the Rutshuru River, the Ntungwe River and the Rwindi River. The lake drains into the Semliki River, which flows northward through DRC to discharge into Lake Albert.

Lake George is a small and shallow lake (270 km^2) with a maximum depth of 4 m. The lake flows into Lake Edward through the Kazinga Channel. Over 78 fish species, belonging to 8 families, have been recorded in lakes Edward and George (Table 2). These fish fauna are dominated by the family Cichlidae with over 60 species [43]. These include haplochromine cichlids, more than 90% of which are endemic, and two tilapiine species, Nile tilapia *Oreochromis niloticus* and *O. leucostictus* [29, 43]. Other fish groups include lungfish and African catfish.

Fishing is an important activity among local residents. Fishing efforts have been increasing gradually during the past few years. The number of fishers increased from 355 in January 2008 to 440 in January 2011. About 16,545 gillnets, 34,350 hooks and lines and 9 traps were operating in the lake in 2011. Unlike lakes Victoria and Kyoga, which have open access, Lake Edward is controlled, with a specified number of boats, with a known number of nets annually. Lake Edward/George and the Kazinga Channel together produced 12,000 tonnes of fish in 1976. In 1989 and 1991, the official annual landings were around 6,000 tonnes. However, it was estimated that the catch estimates should be raised by a factor 2 or 3 due to unreported illegal fishing [44].

3.6 Sudd Wetland

The Sudd is one of the largest wetlands in the world and the largest freshwater wetland in the Nile Basin. It is located in South Sudan and formed by the White Nile's *Baḥr al-Jabal* section. The size of the Sudd and adjacent areas is highly variable, averaging 30,000 km^2 [45, 46]. During the wet season, it may extend to over 130,000 km^2, depending on the inflowing waters from Lake Victoria, which is the main factor controlling flood levels and area inundation. The total area of the Sudd is also related to the amount of water reaching Bor from Albert Nile and from floods or seasonal watercourses.

About 68 fish species, belonging to 21 families, were recorded in Sudd wetlands (Table 2). Families Cyprinidae (nine species), Mormyridae (eight species) and Cichlidae (seven species), Alestiidae, Distichodontidae, Mochokidae and Bagridae (five species each) are the most dominant.

While South Sudan has vast aquatic and fisheries resources with over 130 fish species reported, the full potential of these has yet to be exploited. This is mainly due to the lack of processing and storage facilities and inadequate transportation infrastructure, both of which have limited the development of commercial fisheries. The Sudd is also covered with heavy vegetation, which makes stock assessment a difficult job.

The potential fish yield of the Sudd has been estimated at 75,000 tonnes per year [30]. However, approximately 143,000 tonnes of fish are caught annually from these water sources, valued at US$ 510 million [45, 46]. Two-thirds of this catch is harvested during the rainy season (April to September) when the waterbodies are full and with an abundance of stock. Following the rainy season, substantial fishing takes place at the floodplains which have sufficient water retention in the dry season.

The Nile tilapia, *Oreochromis niloticus*, is the most predominant fishery in South Sudan, comprising about 20% of the total capture resource. *Heterotis niloticus*; *Gymnarchus niloticus*; the African catfish, *Clarias gariepinus*, *Alestes* spp.; and the elephant snoutfish, *Mormyrus caschive*, also represent significant contribution to total catch. However, the record for the biggest individual catch per unit weight belongs to the Nile perch, *Lates niloticus*, which are harvested at a weight of up to 30 kg each.

The fisheries of the Sudd region are mainly artisanal and can be divided into subsistence fishery (fishes are used basically for family consumption, leaving occasional surplus for sale or barter) and commercial fishery, where the catch is targeted mainly for trade. In commercial fisheries, the fisher may employ relatively better craft and gear and sometimes engages labour employment. The total number of fishers has been estimated at 220,000, consisting of about 208,000 subsistence fishers and about 12,000 commercial fishers [45, 46]. When necessary, many seasonal or occasional fishers participate in fishing vocation.

3.7 Machar Marshes

The Machar Marshes are a large wetland area comprising lakes and floodplains, located in the eastern part of South Sudan (state of Upper Nile) and western Ethiopia, east of the White Nile and north of the Sobat River, between 8°27′–9°58′N and 32°11′–34°9′E. The sizes of Machar Marches vary, with an estimated area of about 9,000 km^2, 55% of which are located in South Sudan and 45% in Ethiopia [47]. The marshes are fed by flows from the Baro River (through Khor Machar), the Yabus River, the Daga River and the Pibor River and drained by the White Nile (through Adar River).

3.8 Mid-Nile (Sudan and South Sudan)

Over 95% of the Sudanese fish landing is obtained from inland fisheries on the Nile, its tributaries and associated swamps. The White Nile, the Blue Nile, their tributaries and the five man-made lakes of Gebel Aulia, Roseires, Khashm El-Girba, Sennar and Nubia are the main inland fishing areas in Sudan. The waters of these rivers, wetlands and lakes have substantial fisheries resources that have been traditionally exploited for subsistence. However, these fisheries have been slowly expanding during the recent years, due to the limited information on production statistics and lack of skilled and experienced workforce.

The River Nile, with the confluence of the White Nile and the Blue Nile at Khartoum, is the most important inland water source in Sudan. The potential yield of Lake Nubia was estimated at 5,100 tonnes y^{-1}, while the landing was only 1,000 tonnes in 2003. Of the other man-made reservoirs, Gebel Aulia in the White Nile and Sennar and Roseires in the Blue Nile, especially Gebel Aulia Reservoir, were significantly important. These water sources contributed 13,000, 1,000 and 1,500 tonnes, respectively, to the inland fisheries of Sudan in 2003 [30].

In the Sudanese inland fresh water, fish landing is dominated by the following species and species groups: *Gymnarchus* sp., *Heterotis* spp., *Citharinus* spp., *Clarias* spp., *Lates niloticus*, *Tilapia* spp., *Oreochromis* spp., *Labeo* spp., *Alestes* spp., *Distichodus* spp., *Barbus binny*, *Bagrus* spp. and the family Schilbeidae. In South Sudan, Nile tilapia (*Oreochromis niloticus*) is by far the most predominant fishery, comprising up to 20% of the total inland fisheries [46]. *Heterotis niloticus*, *Gymnarchus niloticus*, the African catfish (*Clarias gariepinus*), Nile perch (*Lates niloticus*), *Alestes* spp. and the elephant snoutfish (*Mormyrus caschive*) represent significant contribution to catch amounts.

Subsistence, artisanal and commercial fisheries are practised in mid-Nile inland fisheries. Subsistence fishing is based upon the spear, line and cast nets used from the banks or from canoes and papyrus rafts. Traditional craft, including oar-powered papyrus rafts and poled dugout canoes, are also widely used. Commercial fisheries are also gradually expanding, particularly in Sudan, using simple motorized steel vessels and planked boats. However, fishing techniques and craft employed in these fisheries remain largely artisanal [45]. Fishing gear and methods include traditional traps, spear, longlines, hook-and-line, drifting gillnets, beach seines and trammel nets.

3.9 Lakes Nasser and Nubia

Lake Nasser is a huge man-made reservoir behind the High Dam in Egypt. It is about 500 km long and 35 km wide at its widest point, with surface area of 5,237 km ^{2} at 182 m water level and a storage capacity of some 150–165 km^3 of water [48, 49]. The lake is partitioned into Lake Nasser in Egypt (about 300 km long) and Lake Nubia in Sudan (about 196 km long). The lake is also characterized with several dendritic inlets, or side extensions, known as *khor* (pl. *kheran*). Kheran are important fishing, spawning and nursing grounds for many fish species, particularly cichlid fishes.

Fish fauna of Lake Nasser comprise 56 species belonging to 17 families, with families Cichlidae (4 species), Cyprinidae (13 species), Latidae (1 species), Alestidae (6 species) and Bagridae (2 species) being the most important. Tilapias form the bulk of the annual catch in Lake Nasser, followed by Nile perch. During the past two decades, tilapia contribution ranged from 40 to 90%, followed by Nile perch (5–25%) and barb (*Labeo niloticus*) (5–10%) [50, 51]. During this period, the annual landing of Lake Nasser has been sharply declined (from 50,930 tonnes in 1995 to 18,716 tonnes in 2013 [50, 51].

The common fishing methods in Lake Nasser fisheries are trammel net (*duk*), top-set gillnet (*sakarota*), bottom-set gillnet (*kobok*), beach seine net (*gorrafa*) and longline [10]. Trammel nets are generally used in the northern part of the lake, while in the southern part top-set gillnets and mid-water or bottom-set gillnets predominate. Beach seine is operated during daytime fishing and used mainly for catching tilapiine species. Longline fishing is generally limited, but is more common in the southern part of the lake than in the northern part. It is used in deep waters to catch Nile perch (samoos) and Bagrid fish (bayad) with bolti (tilapia) and lebeis (*Labeo* spp.).

In the late 1960s, 43 fish species were recorded in Lake Nubia [52]. However, only 26 fish species belonging to 10 families (Table 2) were recorded in 1975/1976 [8]. This decline was due to that some species that were economically important during the early years of the lake were later negligible (e.g. *Distichodus*, *Citharinus*, *Bagrus*) [52].

Characidae, Cyprinidae and Schilbeidae are the most abundant followed by Mochokidae and Centropomidae. As in Lake Nasser, tilapias are the most important commercial fish, but Nile perch is gaining more economic importance. It should be mentioned, however, that *Distichodus* spp. (Lessan El-Bagar), *Citharinus* (Kamara) and *Bagrus*, which used to represent a major part of the commercial landing during the late 1960s, have almost disappeared [52]. There are temporal and spatial variations in fish abundance in Lake Nubia. For example, the western and southern regions have higher catches than the rest of the lake. *Bagrus* and *Synodontis* are also abundant during spring (March–May), while the abundance of *Lates* and the *Labeo* increases in August and September during the flood season. The potential yield was estimated at 5,100 tonnes/year (A.I. El-Moghraby, unpublished; cited in [30]).

As mentioned in Sect. 3.8, traditional fishing methods, including spear, line, cast nets, oar-powered papyrus rafts, poled dugout canoes, hook-and-line, drifting gillnets, beach seines and trammel nets, are used in Lake Nubia. Commercial artisanal fisheries are also expanding, using simple motorized steel vessels and planked boats.

4 Major Issues and Challenges Facing Nile Basin Fisheries

The major challenges and threats to fisheries resources in the Nile Basin are:

- Species introductions
- Degradation of aquatic habitats and biodiversity
- Unsustainable fishing practices
- Pollution and eutrophication resulting from human populations
- Invasive weeds

4.1 Species Introductions

Fish introductions are the movements of fish species beyond its present geographical range into a new environment, to establish new taxa. The main reasons for fish introductions in Nile Basin lakes (Lake Victoria, Kenya) were [53]:

1. Enhancement and/or supplement stocks in order to improve the fisheries
2. Recreation (aquarium/ornamental fisheries)
3. Providing sport fish to attract tourism
4. Filling an apparently vacant niche
5. Controlling weeds and disease vectors, mosquitoes and snails
6. Create a commercial fishery

Fish introductions can be unsuccessful, successful or successful but with high environmental costs ranging from habitat destruction and hybridization with endemic species to disappearance of native species. Introductions of a number of fish species into different Nile Basin lakes have been well documented. Some introductions succeeded, while others failed. One of the most successful examples is the introduction of Nile tilapia (*Oreochromis niloticus*) into Lake Victoria (Uganda) in the early 1900s. However, this introduction contributed to the decline or disappearance of native tilapia from the Lake Victoria fisheries. The native tilapiines, *Oreochromis esculentus* and *Oreochromis variabilis*, declined due to hybridization and competition with *Oreochromis niloticus* [54]. Currently, Nile tilapia is the most dominant tilapia species in Lake Victoria region and second only to another introduced, non-cichlid species, Nile perch (*Lates niloticus*), in commercial value [55].

Fish catches in Lake Victoria increased about six times following establishment of Nile perch. Unfortunately, this introduction was accompanied by a decline or disappearance of most of the native fish species. For example, haplochromine stocks, which were the most abundant fish in Lake Victoria and formed 80% of the fish stocks [56, 57] comprising of over 500 species [58], severely declined, and 60% of the species may have become extinct due to predation by the Nile perch [16]. Introduced redbelly tilapia (*Tilapia zillii*) have also been reported to compete with the endemic *O. variabilis* in Lake Victoria, leading to severe threat and risk due to that species [59].

4.2 Degradation of Aquatic Habitats

The degradation of fisheries and aquatic habitats of Nile Basin lakes, rivers and wetlands have been occurring for several decades. Fisheries degradation generally starts with human population growth, followed by over-exploitation of these resources, leading to a decline in fish stocks. Consequently, the introduction of new fish species to improve catches occurred in many lakes and wetlands [60].

As mentioned earlier, the introduction of Nile perch into Lake Victoria has sharply reduced the native species. Poor farming patterns and waste disposal have led to nutrient enrichment in the lake. Nutrient enrichment and climate warming have contributed to deoxygenation of deepwater habitats in the lake and promoted algal blooms and changes in the lower food web. These changes have made the Lake Victoria ecosystem biologically sensitive to both the radiation balance and the water budget [61].

4.3 Unsustainable Fishing Practices

Originally, fishing effort on most of the Nile Basin lakes was limited due to the low number of fishers, poor fishing crafts, inefficient traditional fishing gear and poor fish processing and poor handling and marketing channels. The human populations in the Nile Basin countries have been increasing over the years. This was accompanied with a parallel increase in fishing efforts and improvements in fishing crafts. As a result, most fisheries in Nile Basin lakes have declined; and some fisheries have even completely collapsed. The use of unsustainable, and sometimes destructive, fishing gears has also contributed to the decline in fish stocks. For example, overfishing has also had an effect on Nile perch in Lake Victoria and Lake Kyoga where the populations of these fish have declined sharply. The capture of immature fish, weak management and extension systems, inefficient dissemination of management information, outdated fisheries laws and regulations and inadequate enforcement of laws and regulations have also contributed to the decline in the fish stocks.

Similarly, the unsustainable fishing practices have negatively affected some fish species in Lake Tana (Ethiopia). De Graaf et al. [62] reported that motorized, commercial gillnet fishery targeting the spawning aggregations of *Barbus* species (Cyprinidae), together with recruitment overfishing, resulted in considerable decline in their juvenile stocks. In addition, fish stocks in lakes Edward and Albert, in terms of species diversity and production, have been reported to be declining due to overfishing and bad fishing practices.

4.4 Pollution and Eutrophication

The changes in physical, chemical and biological characteristics of the aquatic environments can significantly affect the fauna, flora and overall biodiversity of these environments. The Nile Basin lakes and wetlands have experienced considerable change over several decades. For example, over the last three decades, Lake Victoria has been subject to nutrient enrichment from human activities in the catchment areas, industrial and domestic sewage inputs and wastewater from combustion processes [63–65]. This has led to significant increase in eutrophication, which in turn resulted in sharp increase in algal biomass (especially blue green algae) and phytoplankton production. Consequently, water transparency and oxygen concentration decreased, leading to loss in fish habitat.

The pollution of lakes Edward and Albert and their catchments from domestic sewage, agricultural inputs and mining have also sharply contributed to deterioration of water quality in the lakes. The expanding population in the catchment areas of the two lakes, particularly at the fishing villages and landing sites, has also increased the demand for land and fuel wood, leading to deforestation, and, in turn, causing loss of ecosystem habitats. Deforestation has also resulted in increased levels of suspended solids in watercourses which ultimately end up in the lakes, leading to a significant impact on their biodiversity.

4.5 Invasive Weeds

The invasion of aquatic weeds is a major challenge to fisheries management in Nile Basin lakes and catchments. Water hyacinth (*Eichhornia crassipes*) is the most problematic invasive weed in Lake Victoria. This exotic weed has grown tremendously during the past few decades to become the biggest menace in the lake. It generally covers shallow sheltered areas which are the most suitable breeding and nursery grounds for fish. This weed also impedes boat traffic, blocks irrigation channels and interferes with hydropower generation and water treatment plants. It also reduces light penetration in water column and causes oxygen depletion in the water it covers, which in turn reduces fish breeding and nursery grounds. The proliferation of water hyacinth has also been associated with nutrient enrichment of the waterbodies, leading to eutrophication of these water masses.

In Lake Kyoga, shallow areas (less than 3 m deep) are covered completely with macrophytes, especially water hyacinth and lilies. Water hyacinth has become a permanent component of the lake system. Swampy zone fringing the shoreline is covered mainly with papyrus.

4.6 Problems of Aquaculture

There are several constraints that hamper the development of aquaculture in Africa, including Nile Basin countries. These constraints are listed as follows [66–68]:

1. Severe political instability in some Nile Basin countries limits the development of aquaculture. Such political problems also threaten the economic viability of aquaculture enterprises and security of investment.
2. Poverty of consumers, leading to small local markets and reliance on external markets.
3. The poor infrastructure, including poor storage, poor marketing channels and poor maintenance of farming facilities.
4. Poor quality of governmental services, such as extension, capacity building and law enforcement.
5. Sociocultural constraints.
6. Shortage of good-quality seed (larvae) and feeds.
7. Shortage or lack of governmental budgets allocated for aquaculture.
8. Lack of local expertise, experienced labour and technical experience in aquaculture practices including farming systems, water quality management, fish

health management, feeding strategies, larval production and rearing, etc. This may increase the risk of enterprise and limit technical options.
9. The dependence, to a large extent, on external donations and technologies. In most cases, the farmers do not have the necessary experience and training in these new technologies, and the governments do not provide the necessary support.
10. Poor access to, and dissemination of, good quality and timely information in the most appropriate formats and approaches, in support of responsible aquaculture and trade.
11. The severe competition of aquaculture with other resource (land/water/feed) users.
12. Poor integration of aquaculture with other farming activities.
13. Lack of market-driven agenda and governance limitations.
14. Lack or limitation of aquaculture research and development.

These constrains should be addressed by Nile Basin states, both individually and cooperatively, if aquaculture is to be developed sustainably. The international organizations and fund providers, which are concerned with aquaculture development (such as the FAO and the European Union (EU)), should also provide more assistance to overcome these constraints and to promote aquaculture development in the region.

5 Management Plans and Efforts

There is an urgent need to address the management issues and to reduce threats to Nile Basin lakes and wetlands and sustain their fisheries. The required actions include:

1. Control of population increases in lake basins.
2. Management of fisheries resources sustainably. This includes:
   (a) Controlling fishing effort (boats, horsepower, gears, number of fishers, number of fish processing plants, etc.)
   (b) Regulating fishing gears and methods and improving their efficiencies
   (c) Eliminating the use of destructive fishing gears and methods
   (d) Controlling capture of immature fish
   (e) Promoting fisheries statistics and data collection
   (f) Encouragement of fish and fisheries research (fish biology, stock assessment, population dynamics, etc.)
   (g) Promoting aquaculture
   (h) Improving the livelihood of fishermen and their families
   (i) Developing and promoting appropriate transportation, handling, storage, processing and marketing methods

(j) Providing the necessary capacity building (education, training, extension services, etc.) to the fishers, supporting industries and decision-makers

3. Provide the necessary restrictions and guidelines to control species introductions.
4. Conserve and sustainably use aquatic biodiversity.
5. Prevent and control eutrophication and pollution.
6. Control the use and dumping of pesticide and herbicide residues.
7. Control invasive weeds.
8. Set up and enforce appropriate laws, regulations and policies to sustainably manage the fisheries resources and their habitats in the Nile Basin.
9. Develop efficient and effective institutions and institutional processes and governance which involve stakeholders in planning and implementation.
10. Develop sustainable funding mechanisms for implementing fisheries programmes.
11. Provide adequate financial resources and human capacity to implement fisheries management programmes.

To implement these actions, several initiatives, projects, case studies, conferences and workshops have been carried out in most of the basin countries. Most African governments have also received financial and technical support from UN agencies such as UNICEF and UNFPA, and also from the European Union (EU), for implementation. The EU has provided support over the last two decades to establish and implement the "Fisheries Management Plan" for Lake Victoria. Such support will assist the Lake Victoria Fisheries Organization (LVFO) to develop and implement fisheries policies and legislation and manage the fisheries on sound basis.

In the past, there was no harmony in the management measures governing Lake Victoria resources; and each country used to adopt different measures. The formation of Lake Victoria Fisheries Organization (LVFO) helped these governments to implement a management plan, to harmonize fisheries policies and regulations and also to develop standard operational procedures. Accordingly, wide management regulations have been established and co-management approaches adopted.

A number of projects have also been conducted to conserve aquatic ecosystems and biodiversity of Nile Basin lakes. For example, there have been efforts to conserve ecosystems, species and genetic diversity especially in Lake Victoria with support of the Global Environment Facility (GEF) through the Lake Victoria Environmental Management Project (LVEMP). Similarly, the LVEMP project funded by GEF and the World Bank provided support to Kenya, Tanzania and Uganda to study the establishment modalities for setting a trust fund. The implication of the fund has been hindered in Kenya and Uganda because they require the money collected to be surrendered to the national treasury, while Tanzania allows for use of the fund directly in fisheries development activities.

References

1. Awulachew SB, Smakhtin V, Molden D, Peden D (2012) The Nile River Basin. Water, agriculture, governance and livelihoods. Routledge, 2 Park Square, Milton Park, Abingdon, Oxon OX14 4RN. 316 pp
2. Kinyangi J, Peden D, Herrero M, Tsige A, Ouna T, Notenbaert A (2012) The Nile Basin, people, poverty and vulnerability. In: Awulachew SB, Smakhtin V, Molden D, Peden D (eds) The Nile River Basin. Water, agriculture, governance and livelihoods. Routledge, 2 Park Square, Milton Park, Abingdon, Oxon OX14 4RN, pp 30–46
3. FAO (Food and Agriculture Organization of the United Nations) (1997) Irrigation potential in Africa: a basin approach, FAO Land and Water Bulletin, 4. www.fao.org/docrep/W4347E/W4347E00.htm. Accessed 28 Dec 2011
4. Roškar J (2000) Assessing the water resources potential of the Nile River based on data, available at the Nile forecasting center in Cairo. Geografski zbornik 53:32–65
5. Howell PP, Lock M, Cobb S (1988) The Jonglei Canal: impact and opportunity. Cambridge University Press, Cambridge
6. Hamza W (2014) The Nile fishes and fisheries. In: Grillo O (ed) Biodiversity - the dynamic balance of the planet. Intech, pp 349–370
7. FAO (2015a) Global Capture Production 1950–2013. http://www.fao.org/fishery/statistics/global-capture-production/query/en
8. Ali MT (1984) Fishes and fisheries of Lake Nubia, Sudan. Hydrobiologia 110:305–314
9. Witte F, van Oijen MJP, Ferdinand A, Sibbing FA (2009a) Fish Fauna of the Nile. In: Dumont HJ (ed) The Nile: origin, environments, limnology and human use. Springer Science + Business Media B.V., pp 647–675
10. van Zwieten PAM, Béné C, Kolding J, Brummett R, Valbo-Jørgensen J (eds) (2011) Review of tropical reservoirs and their fisheries – the cases of Lake Nasser, Lake Volta and Indo-Gangetic Basin reservoirs. FAO Fisheries and Aquaculture Technical Paper. No. 557. Rome, FAO, 148 pp
11. LVFO (Lake Victoria Fisheries Organization) (2013) Regional status report on Lake Victoria bi-ennial frame surveys between 2000 and 2012, Kenya, Tanzania and Uganda. Regional Frame Survey Report 2012, 64 pp
12. World Bank (2009) LVEMP II Project Appraisal Document. Report No. 45313-AFR, 197 pp. http://wldb.ilec.or.jp/data/databook_html/afr/afr-15.html
13. LVFO (Lake Victoria Fisheries Organization) (2011) State of fish stocks. www.lvfo.org
14. Aliro EB (2010) Lake Victoria fisheries. FIRST Magazine. East African Community (EAC), pp 34–37 (http://www.firstmagazine.com/Publishing/SpecialistPublishingDetail.aspx?SpecialistPublicationId=24)
15. Lowe-McConnell R (2009) Fisheries and cichlid evolution in the African Great Lakes: progress and problems. Freshw Rev 2:131–151
16. Witte F, Goldscmidt T, Goudswaard P, Ligtvoet W, van Oijen M, Wanink JH (1992) Species extinction and concomitant changes in Lake Victoria. Neth J Zool 42:214–232
17. Ojuok JE, Njiru M, Ntiba MJ, Mavuti KM (2007) The effect of overfishing on the life–history strategies of Nile tilapia, *Orechromis niloticus* (L.) in the Nyanza Gulf of Lake Victoria, Kenya. Aquat Ecosyst Health Manage 10:443–448
18. Manyala JO, Ojuok JE (2007) Survival of the Lake Victoria *Rastrineobola argentea* in a rapidly changing environment: biotic and abiotic interactions. Aquat Ecosyst Health Manage 10:407–415
19. Katunzi EFB, Zoutendijk J, Goldschmidt T, Wanink JH, Witte F (2003) Lost zooplanktivorous cichlid from Lake Victoria reappears with a new trade. Ecol Freshw Fish 12:237–240
20. Kishe-Machumu M, Witte F, Wanink JH (2008) Dietary shift in benthivorous cichlids after the ecological changes in Lake Victoria. Anim Biol 58:401–417

21. Wanink JH (1998) The pelagic cyprinid *Rastrineobola argentea* as a crucial link in the disrupted ecosystem of Lake Victoria. Ph.D. Dissertation, University of Leiden, Leiden, The Netherlands
22. Njiru M, Okeyo-Owuor JB, Muchiri M, Cowx IG, van der Knaap M (2007) Changes in population characteristics and diet of Nile tilapia *Oreochromis niloticus* (L.) from Nyanza Gulf of Lake Victoria, Kenya: what are the management options? Aquat Ecosyst Health Manage 10:434–442
23. Olowo JP, Chapman LJ (1999) Trophic shifts in predatory catfishes following the introduction of Nile perch into Lake Victoria. Afr J Ecol 37:457–470
24. Wanink JH, Joordens JCA (2007) Dietary shifts in *Brycinus sadleri* (Pisces: Characidae) from southern Lake Victoria. Aquat Ecosyst Health Manage 10:392–397
25. Chapman LJ, Chapman CA, Kaufman L, Witte F, Balirwa J (2008) Biodiversity conservation in African inland waters: lessons of the Lake Victoria Basin. Verhandlungen der Internationalen Vereinigung für Limnologie 30:16–34
26. Witte F, Welten M, Heemskerk MB, van der Stap I, Ham L, Rutjes HA, Wanink J (2008) Major morphological changes in a Lake Victoria fish within two decades. Biol J Linn Soc 94:41–52
27. MNRT (1996) Fisheries statistical annual report. Dar-es-Salaam, Tanzania, 37 pp
28. Greenwood PH (1966) The fishes of Uganda. The Uganda Society, Kampala
29. Greenwood PH (1974) The cichlid fishes of Lake Victoria, East Africa: the biology and evolution of a species flock. Bull Brit Mus (Nat Hist) Zool Ser Suppl 6:1–134
30. Witte F, de Graaf M, Mkumbo OC, El-Moghraby AI, Sibbing FA (2009b) Fisheries in the Nile system. In: Dumont HJ (ed) The Nile, Monographiae Biologicae 89. Springer, Dordrecht, The Netherlands, pp 723–748
31. Ogutu-Ohwayo R (1990) The decline of the native fishes of lakes Victoria and Kyoga (East Africa) and the impact of introduced species, especially the Nile perch, *Lates niloticus*, and the Nile tilapia, *Oreochromis niloticus*. Environ Biol Fishes 27:81–96
32. Wudneh T (1998) Biology and management of fish stocks in Bahir Dar Gulf, Lake Tana, Ethiopia. Ph.D. Dissertation, Wageningen, Agricultural University institute of Animal Science. The Netherlands, 143 pp
33. Kokebe DT (2014) Spatial and temporal distributions and some biological aspects of commercially important fish species of Lake Tana, Ethiopia. J Coast Life Med 2(8):589–595
34. Sibbing FA, Nagelkerke LAJ (2001) Resource partitioning by Lake Tana barbs predicted from fish morphometrics and prey characteristics. Rev Fish Biol Fish 10:393–437
35. LFDP (1998) Lake Fisheries Development Project phase II, Ministry of Agriculture and EEC, Final Report of fisheries biologist. GOPA-Consultants, July 1998, 198 pp
36. Lemma B (2012) Report on the value Chain Assessment of the Fishery Sector in Ethiopia. Food and Agriculture Organization, Sub-Regional Office for Eastern Africa, Addis Ababa, 131 pp
37. Chekol AA (2013) Management and livelihood opportunity of Lake Tana Fishery, Ethiopia: the need for co management. Master Thesis in International Fisheries Management. Norwegian College of Fisheries Science
38. Taabu-Munyaho A, Mbabazi D, Nakiyende H, Bassa S, Muhumuza E, Nsega M, Byekwaso A, Amiina R, Balirwa JS (2012) Report of catch assessment survey of Lake Albert-Albert Nile conducted in July 2012. National Fisheries Resources Research Institute (NaFIRRI), 17 pp
39. Wandera SB, Balirwa JS (2010) Fish species diversity and relative abundance in Lake Albert-Uganda. Aquat Ecosyst Health Manage 13:284–293
40. Greenwood PH (1976) Fish fauna of the Nile. In: Rzóska J (ed) The Nile: biology of an ancient river. Monographiae Biologicae 29. Junk, The Hague, pp 127–141
41. Trewavas E (1983) Tilapiine fishes of the genera *Sarotherodon, Oreochromis* and *Danakilia*. British Museum (Natural History), London
42. NaFIRRI FS and CAS Reports (2007) Report on frame and catch assessment surveys on Lake Albert. National Fisheries Resources Research Institute, NARO, January 2007, Jinja, Uganda

43. Snoeks J (2000) How well known is the ichthyodiversity of the large East African Lakes? Adv Ecol Res 31:553–565
44. Coenen EJ (ed) (1991) First UGASTAT CAS Results for Lakes Victoria, Albert and the Edward/George-Kazinga Channel Complex by UGA/87/007 Biostat Group. FAO/UNDP Fisheries Statistics and Information Systems (FISHIN) Project, Biostat Report Series, vol 5, no 27. FAO, Rome
45. FAO (2015b) Fishery and Aquaculture Country Profiles for the Republic of Sudan (on line). file:///D:/Nile%20fishes/Nile%20Delta/Nile%20basin/Sudan-%20Fishery%20and%20Aquaculture%20Country%20Profiles.pdf
46. FAO (2015c) Fishery and Aquaculture Country Profiles for the Republic of South Sudan (on line). file:///D:/Nile%20fishes/Nile%20Delta/Nile%20basin/South%20Sudan-%20Fishery%20and%20Aquaculture%20Country%20Profiles.pdf
47. Hughes RH, Hughes JS (1992) A directory of African wetlands. International Union for the Conservation of Nature, Gland, Switzerland, United Nations Environment Programme, Nairobi, Kenya and World Conservation Monitoring Centre, Cambridge
48. El-Gohary FA (1989) Egypt and the River Nile: protection of the environment of the River Nile Basin. In: Hassan F (ed) Proceedings of a regional symposium in Cairo. The Scientific Association of Arab Women in Egypt, pp 56–74
49. Latif AFA (1979) Effect of impoundment on Nile biota in Lake Nasser. In: Proceedings of the international symposium environmental effects of hydraulic engineering works. Tennessee Valley Authority, Knoxville, USA, pp 435–445
50. GAFRD (General authority for Fish resources Development) (2005) Fish statistic Year Book 2003. Ministry of Agriculture and Land Reclamation, Cairo, Egypt
51. GAFRD (General authority for Fish resources Development) (2015) Fish statistic Year Book 2013. Ministry of Agriculture and Land Reclamation, Cairo, Egypt
52. El-Shabrawy GM (2009) Lake Nasser–Nubia. In: Dumont HJ (ed) The Nile: origin, environments, limnology and human use, 723. Springer Science + Business Media B.V., pp 125–155
53. Mboya DO, Manyala JO, Ngugi CC (2001) Fish introductions and their impact on the biodiversity and the fisheries of Lake Victoria. Fisheries Department, Kisumu, Kenya, 11 pp
54. Njiru M, Mkumbo OC, van der Knaap M (2010) Some possible factors leading to decline in fish species in Lake Victoria. Aquat Ecosyst Health Manage 13:3–10
55. Fuerst PA, Mwanja WW, Kaufman L (2000) The genetic history of the introduced Nile tilapia of Lake Victoria (Uganda – E. Africa): the population structure of *Oreochromis niloticus* (Pisces: Cichlidae) revealed by DNA microsatellite markers. In: Fitzsimmons K, Filho JC (eds) Tilapia culture in the 21st century. Proceedings from the fifth international symposium on Tilapia aquaculture. *Rio de Janeiro, Brazil*. American Tilapia Association, Charles Town, West Virginia, and ICLARM, Penang, Malaysia, pp 30–40
56. Kudhongania AW, Cordone AJ (1974) Batho-spatial distribution patterns and biomass estimate of the major demersal fishes in Lake Victoria. Afr J Trop Hydrobiol Fish 3:15–31
57. Okaronon J, Acere T, Ocenodongo D (1985) The current state of the fisheries in the northern portion of Lake Victoria (Uganda). FAO Fish Rep 335:89–98
58. Seahausen O (1996) Lake Victoria Rock Cichlids: taxonomy, ecology, and distribution. Verduijn Cichlids, Zevenhuizen, 304 pp
59. Welcomme RL (1988) International introductions of inland aquatic species. FAO Fisheries Technical Paper No. 294. FAO, Rome, pp 1–318
60. Ogutu-Ohwayo R, Hecky RE (1991) Fish introductions in Africa and some of their implications. Can J Fish Aquat Sci 48(Suppl 1):8–12
61. Lehman JT (2009) Lake Victoria. In: Dumont HJ (ed) The Nile, vol 89, Monographiae Biologicae. Springer, Dordrecht, pp 215–241
62. de Graaf M, Machiels MAM, Wudneh T, Sibbing FA (2004) Declining stocks of Lake Tana's endemic *Barbus* species flock (Pisces, Cyprinidae): natural variation or human impact? Biol Conserv 116:277–287

63. Bootsma H, Hecky RE (1993) Conservation of the African Great Lakes: limnological perspective. Conserv Biol 7:644–656
64. Hecky RE (1993) The eutrophication of Lake Victoria. Verhandlungen der Internationalen Vereinigung für Limnologie 25:39–48
65. Hecky RE, Mugidde R, Ramlal PS, Talbot MR, Kling GW (2010) Multiple stressors cause rapid ecosystem change in Lake Victoria. Freshw Biol 55:19–42
66. Brummett RE, Williams MJ (2000) The evolution of aquaculture in African rural and economic development. Ecol Econ 33:193–203
67. ICLARM–GTZ (1991) The context of small-scale integrated agriculture–aquaculture systems in Africa: a case study of Malawi. ICLARM, Manila, Philippines
68. Satia BP (2011) Regional review on status and trends in aquaculture in Sub-Saharan Africa – 2010. FAO Fisheries and Aquaculture Circular No. 1061/4. Rome, FAO, 152 pp

Part IV
Upper Nile Challenges and Opportunities

Trend Analysis of Precipitation Data: A Case Study of Blue Nile Basin, Africa

Osama Ragab and Abdelaziem Negm

Abstract Implementation of water management policies requires decision support system tools in order to evaluate available water resources and create awareness of possible threats such as floods and droughts. Modelling is one of these decision support tools. However, in developing countries, they do not lack only appropriate tools and personnel to develop and maintain water resources model, but they do not have sufficient data to build, calibrate and validate models. For instance, the rain gauge network is too sparse to produce reliable areal rainfall estimation. Blue Nile Basin is one of the basins that suffer from this problem. Consequently, it can effect on the drainages countries like Sudan and Egypt if it is not managed. In order to develop management, different sources other than ground collected data should be used. Radar technology for topography is not feasible based on the high cost. Another alternative is remote sensed data and its derivatives. This chapter gives an assessment for the availability and quality of remote sensed and global rainfall data as one of the important forcing data which should be used to set up a hydrological model.

Keywords Blue Nile Basin, Rainfall, Remote sensing, Spatial, Temporal

O. Ragab (✉)
Department of Civil Engineering, Faculty of Engineering, Sohar University (formerly at Alexandria University, Alexandria, Egypt), Sohar, Oman
e-mail: Oibrahim@soharuni.edu.om; oSamaRagab241@gmail.com

A. Negm
Department of Water and Water Structure Engineering, Faculty of Engineering, Zagazig University (formerly at Egypt-Japan University of Science and Technology, Alexandria, Egypt), Zagazig, Egypt
e-mail: amnegm@zu.edu.eg; amnegm85@yahoo.com; negm@ejust.edu.eg

A.M. Negm (ed.), *The Nile River*,
Hdb Env Chem (2017) 56: 415–450, DOI 10.1007/698_2016_114,

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1 Introduction

Water resources planning and management is becoming a hot topic of sustainable development and environment protection. Water is a limited resource; its availability depends up on region and climatic conditions. Water can be scarce in some areas, and where available mismanagement and pollution are threats to water supply and irrigation. In developing countries, population growth together with changes in lifestyle and economic development has heightened the pressure on water resources that are already limited. Environmental problems, especially climate change, add to these pressures. A sound water management policy would be a key element in solving water related problem such as poverty and conflicts in trans-boundary river basins.

Remote sensing is used in hydrology to estimate rainfall, surface temperature and soil moisture from satellite imagery, which can be used to determine other hydrological processes such as evapo-transpiration. Rainfall estimation from satellite imagery has been used for more than two decades [1]. A number of algorithms have been developed based on images from the infrared sensors. These images give a measure of cloud top temperature that can be used to identify convective storms and deduce rainfall rate [2]. The latest technology is precipitation Radar on broad Tropical Rainfall Measuring Mission (TRMM) satellite, which can measure the vertical structure of troposphere precipitation [3]. Most of these satellite data are available online and free of charge, including precipitation, surface temperature, soil moisture, radiation, relative humidity and wind speed. In most cases, these data are used for climate change models.

Satellite observation is a unique and effective tool to cover a large area homogeneously in a short time. Its advantage is obvious when it observes geophysical parameters varying both in temporally and horizontally, like rainfall. Before satellite observation, it was difficult to estimate the distribution of rainfall over the whole globe regardless of land or ocean. Rainfall observation by rain gauges and ground radars only covers small areas of the Earth's surface, since most of globe is covered with water or is difficult to access.

Currently, the necessary coverage and accuracy is available to estimate precipitation over the whole globe. Although a suite of sensors flying on a variety of satellites has been used to estimate precipitation on a global basis, generally speaking, the performance of satellite precipitation estimates over land areas is highly dependent on the rainfall regime and the temporal and spatial scale of the retrievals. On the other hand, gauge observations continue to play a critical role in observations systems over global land areas. In addition, gauge observations are the only source that is obtained through direct measurements. Both the radar and satellite estimates are indirect in nature and need to be calibrated or verified using the gauge station observations. Although it is possible to create rainfall estimates using a combination of different satellite data (i.e., Climate Prediction Centre morphing technique (COMORPH), researchers have increasingly moved towards using "the best of both worlds" to improve accuracy, coverage and resolution [4].

Precipitation estimates from satellite-based sensors have great potential for hydrological applications, especially as a result of their extensive spatial coverage and fine space and time resolutions. There have been many efforts in operational production of such high-resolution estimates, most notably since the launch of the Tropical Rainfall Measuring Mission (TRMM) in 1997. In addition, ongoing efforts to improve retrieval algorithms and estimation techniques from the community have resulted in newer products [1].

Water is one of several current and future critical issues facing Africa. About 25% of the contemporary African population experience water stress, while 69% live under conditions of relative water abundance. Water supplies from rivers, lakes and rainfall are characterized by their unequal natural geographical distribution and accessibility, and unsustainable water use. By 2025, water availability in eastern Africa will be limited to 1,000–1,700 m^3/person/year. These estimates are based on population growth rates only and climate change has the potential to impose additional pressures on water availability and accessibility (IPCC [5]).

As Ethiopia is undergoing agricultural-based industrialization, climate change should be a concern. Studies done by many researchers indicated that the water resources are sensitive to climate change. Hence, this chapter is targeted to address the impacts of climate change at the basin level (by examining the Blue Nile Basin).

The Blue Nile Basin as located in arid and semi-arid regions are characterized by limited water resources and expanding of urban, industrial and agricultural water requirements will further increase the pressure of accessible groundwater. In semi-arid regions, the precipitation represents a key role of the hydrological cycle. Therefore, reliable estimates of the spatial and temporal rates of precipitation are required to obtain valid estimates of the available water resources [6].

2 Facts and Figures of Blue Nile Basin

2.1 *Blue Nile Basin*

The Blue Nile headwaters emanate at the outlet of Lake Tana in the Ethiopian highlands, as presented in Fig. 1. It is joined by many important tributaries, draining the central and south-western Ethiopian highlands, becoming a mighty river long before it reaches the lowlands and crosses into Sudan. It stretches nearly 850 km between Lake Tana and the Sudan-Ethiopian border, with a fall of 1,300 m; the grades are steeper in the plateau region, and flatter along the low lands. From approximately 30 km downstream of Lake Tana and into Sudan, the river flows through deep rock-cut channels. Very few stream gauges exist along the Blue Nile River within Ethiopia, and those that do tend to have spotty or limited records, and

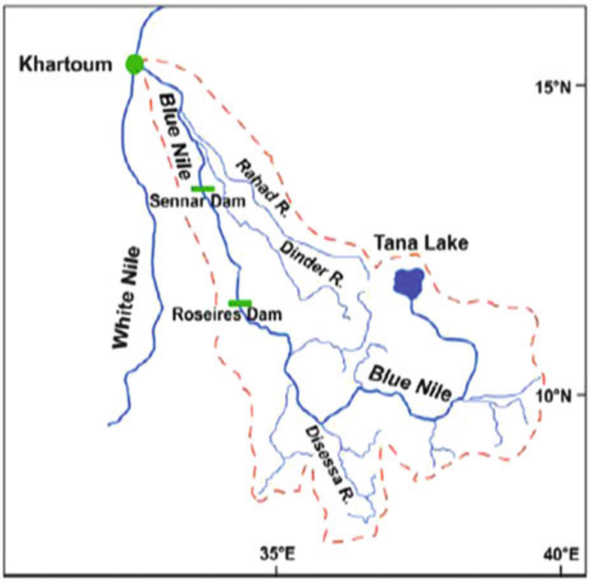

Fig. 1 Location map of Blue Nile Basin and its catchments

are often not publicly available. Upon leaving Lake Tana, the next station location of substantial length is at the Rosaries in Sudan. Stations with shorter records, at Kessie, downstream of Lake Tana, and El Diem, at the Sudan-Ethiopian border, exist, but provide only a few years of monthly flows. The climate in the Blue Nile River basin varies greatly between its inception in the highlands of Ethiopia and its confluence with the White Nile River. Lake Tana sits at 1,830 m above sea level with an annual average precipitation of nearly 1,000 mm and evaporation rates of 1,150 mm per year. Most of the highlands of Ethiopia, at elevations between 1,500 and 3,000 m, are wet, lush and green, and have daily mean temperatures that fluctuate between 15 and 18°C. As the Blue Nile drops into the lowlands and into southern Sudan, rainfall decreases and evaporation increases, resulting in a significant net loss. Temperatures also increase in variability, and reach substantially higher levels than at Lake Tana.

Monthly precipitation records indicate a summer monsoon season, with highest totals in the June–September months. Near Sennar, in Sudan, rains during this season account for nearly 90% of total annual precipitation, while in the Ethiopian highlands, approximately 75% of the annual precipitation falls during the monsoon season. August is typically the peak month, with 2–3 hours of average daily sunshine and humidity levels close to 85% in the Ethiopian highlands.

There are 16 sub-basins in Blue Nile Basin main water resources. Each one has its own characteristics as shown in Table 1.

Table 1 Blue Nile Water resources and its characteristics

No.	Sub-basin name	Area (km^2)	Mean annual rainfall (mm)	Mean annual PET (mm)	Mean annual runoff (mm)	Mean annual flow (m^3/s)
1	Lake Tana	15,320	1,313	1,136	253	3,809
2	N. Gojjam	14,389	1,336	1,242	305	4,389
3	Beshilo	13,242	982	1,140	296	3,920
4	Welaka	6,415	1,072	1,263	323	2,072
5	Jemma	15,782	1,105	1,059	304	4,798
6	S. Gojjam	16,762	1,633	1,183	299	5,012
7	Muger	8,188	1,347	1,210	298	2,440
8	Guder	7,011	910	1,307	312	2,187
9	Fincha	4,089	1,766	1,290	438	1,719
10	Didesa	19,630	1,816	1,308	289	5,673
11	Anger	7,091	1,813	1,318	298	2,355
12	Wenbera	12,957	1,660	1,259	299	3,874
13	Dabus	21,032	2,276	1,112	297	6,246
14	Beles	14,200	1,655	1,274	306	4,345
15	Dinder	14,891	1,504	1,154	188	2,973
16	Rehad	8,269	1,758	1,284	133	1,102

2.2 DEM and Watershed Delineation

HYDRO1k provides a suite of geo-referenced datasets, both raster and vector, which will be of value for all users who need to organize, evaluate or process hydrologic information on a continental scale. It has a spatial resolution approximately 1,000 m. Figure 2 shows the elevation map for Blue Nile river Basin as extracted from the HYDRO1K database.

The watershed delineation and preparation of the DEM were done in ARCGIS10, in order to remove sinks and no void data cells from the original DEM. This helps to improve the delineation and streams definition especially when there are some regions covered by water such as lakes, swamp areas or wetlands, whereby the reflection of electromagnetic radiation used by satellite sensors is poor.

2.3 DEM Setup

The first step of watershed delineation is DEM setup. This concerns analysis of DEM of the watershed which would be used by ARCGIS10 to define the watershed.

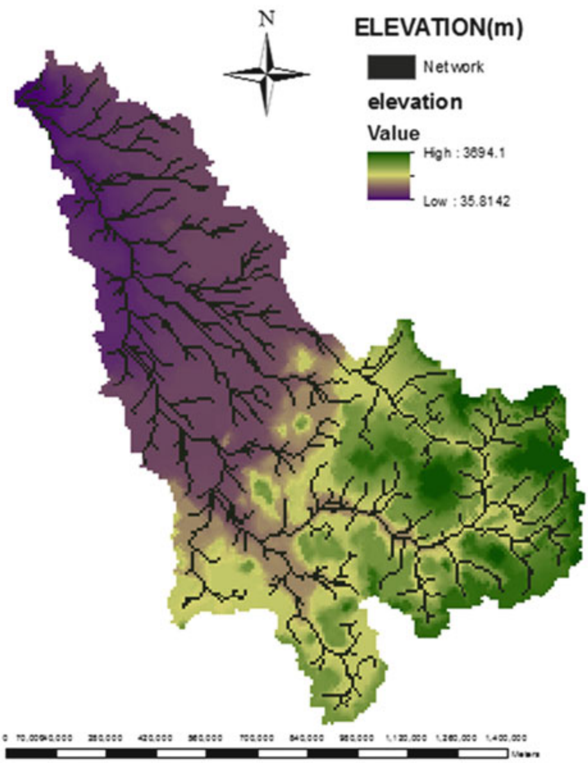

Fig. 2 Blue Nile Basin DEM

Table 2 Blue Nile coordinate system

Projection	Lambert Azimuthal equal area
Geographic coordinate system	GCS_Sphere_ARC_INFO
Longitude of projection centre	35.0
Latitude projection centre	12.0
False easting	0.00
False northing	0.00
Distance units	Meters
Abscissa resolution	1,000
Ordinate resolution	1,000

The DEM should be projected; the projection used is given in Table 2. In this case, the DEM covers a larger area than the area of interest, and a mask was to be provided to set boundaries of the focus area.

2.4 *Stream Definition*

The system proposed here for the delineation and codification of the Earth's river basins is founded upon concepts first articulated by the late Otto Pfafstetter, an engineer with the Department National de Obras de Saneamento (DNOS), a civil works agency of the federal government of Brazil [7]. It is a natural system based upon topographic control of areas drained on the Earth's surface and the topology of the resulting hydrographic network. At the heart of a basin's identity are the size and shape of the catchment area and channel configuration that produce flow at the outlet. All channel reaches have unique direction, and therefore order, and they are arranged in a bifurcated network. The Pfafstetter system is designed to exploit features of the base-10 numbering system that mirror these basin characteristics:

(a) The ordinal nature of digit values from one through nine, and their binary trait of being alternately odd or even.
(b) The ordinal value of a digit indicates relative upstream/downstream position, while a digit's parity indicates network position on or off the main channel.

The objective is the definition of basin identification numbers whose digits can be used in and of themselves to perform basin topological analyses. One important outcome of this strategy is the efficient use of digits. Compared to previous systems, the Pfafstetter system uses significantly fewer digits to uniquely code a population of basins.

As the Pfafstetter system definition stems directly from topography and consequent drainage network topology, it lends itself to implementation through manipulation of digital elevation models (DEMs) and to subsequent exploitation with database management and geographic information system (GIS) software. The

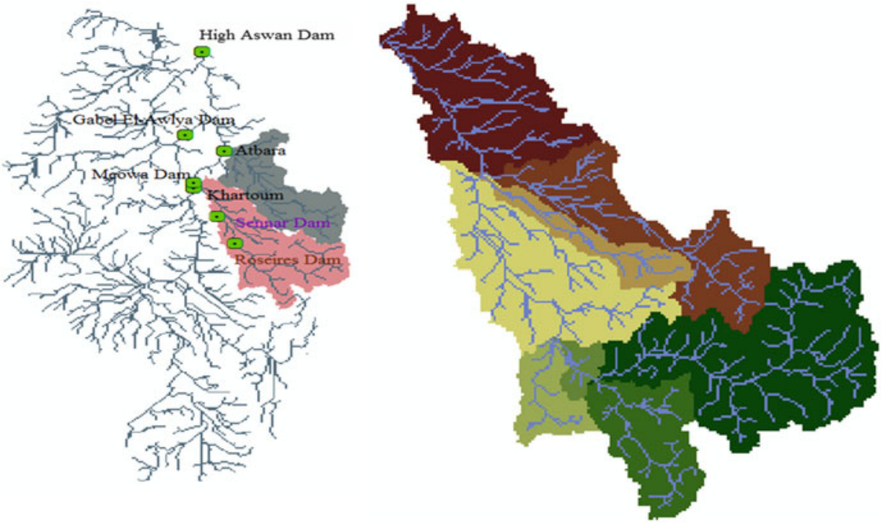

Fig. 3 Streams in Blue Nile Basin

Table 3 Outlet coordinates

Outlet name	Latitude	Longitude
Khartoum	32.644	15.633

appeal of the approach stems from its economy of digits, the topological information that the digits carry and its global applicability. In order to explain the system, it is first necessary to cover basic definitions. An idealized river basin showing subdivision into coded basins and inter-basins for Blue Nile Basin is shown in Fig. 3.

2.5 Outlet and Inlet Definition

The definition of outlets objective is to determine sub-basins. ARCGIS proposes outlets according to stream definition. Table 3 gives the outlets that are provided for the Blue Nile Basin. Sub-basins are delineated from these outlets and each sub-basin is assigned to one stream.

2.6 Soil and Land Use

Land use and soil data are used by hydrologic models to determine the area and the hydrologic parameters of each land-soil category simulated within each sub-basin.

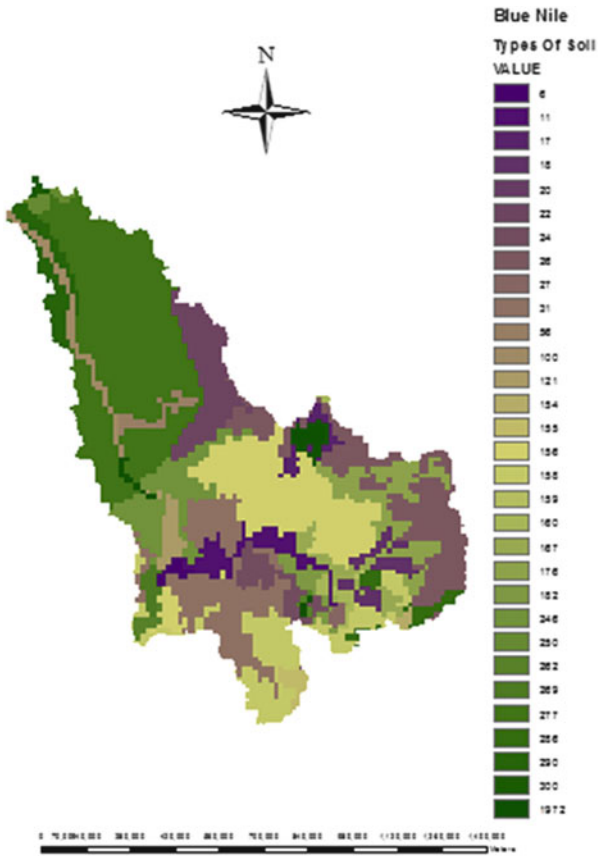

Fig. 4 Soil map of Blue Nile Basin

Soil and land use information are specified as either grid or shape file [8]. The land use and soil themes were projected in the same projection as the DEM used in the watershed delineation. The used soil map is from Food and Agricultural Organization (FAO) world soil classification has a scale of 1:2,500,000. The FAO soil classification defines 31 major soil groups for the Blue Nile Basin and their physical and chemical properties, texture and slope. These soil maps are shown in Fig. 4 and Table 4.

The land use map has a resolution of 1 km resolution and 25 different types of land cover for the Blue Nile Basin. Land use in the Blue Nile basin is dominated by north Sahel sparsely vegetation which covers 38.7%. Other important land use types are barren or sparsely vegetated and Sahara Hammadas with 30.7% and 12.2%, respectively. Water bodies cover 1.38% of the total area of the watershed. Figure 5 and Table 5 show different types of land uses in the Blue Nile Basin as extracted from the Land Sat database.

Table 4 Soil Data in Blue Nile Basin

Code Number	% in Basin	Type of Soil	Texture
6	0.44	A063-3a	Clay
11	2.67	Bd-31-2c	Loam
17	0.91	Be47-2a	Clay-loam
18	1.77	Be48-3c	Clay
20	0.01	Be49-3c	Clay
22	5	Be51-2a	Clay-loam
24	2.08	Be8-3c	Clay
26	9.55	Be9-3c	Clay
27	0.29	Bh11-1b	Sandy-loam
31	8.77	Bh12-3c	Clay-loam
56	0.89	Ge23–2/3a	Clay-loam
100	1.74	Jc2-2a	Loam
121	1.18	Je23-a	Clay-loam
154	0.23	Ne10-3b	Clay
155	0.63	Ne12-2c	Loam
156	12.28	Ne12-3b	Clay
158	6.9	Ne13-3b	Clay
159	0.05	Ne15-3c	Clay
160	0.67	Ne20-3b	Clay
167	1.7	Qc10-1c	Sandy-loam
176	4.65	Qc2-1bc	Sandy-loam
182	1.04	Qc5-1c	Sandy-loam
246	4.93	Re59-2c	Loam
250	0.53	Re65-1a	Loam-sandy
262	0.55	Vc23-3a	Clay
269	0.66	Vc30-3a	Clay
277	24.5	Vc36-3a	Clay
286	1.18	Vp14-3a	Clay
290	2.59	Vp20-3a	Clay
300	0.19	Xh14-1a	Sandy-Clay-Loam
1972	1.38	Water	Water

3 Methods of Precipitation Estimation

Practical limitations of rain gauges for measuring spatially averaged rainfall over large areas and inaccessible areas could be overcome by using remote sensing data which cover larger area especially where there are few gauges or even no gauges. Direct measurement of rainfall from satellites for operational purposes has not been generally feasible because the presence of clouds prevents observation of the precipitation directly with infrared and thermal infrared sensors [9]. However, improved analysis of rainfall is achieved by combining satellite and conventional gauge data [10]. From these observations, estimations of rainfall can be made which

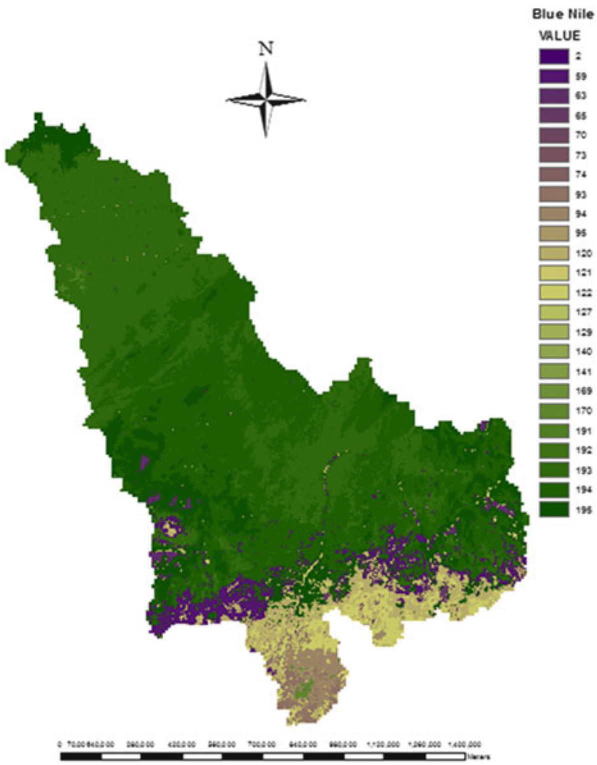

Fig. 5 Land use map of Blue Nile Basin

relate cloud characteristics to instantaneous rainfall rates and cumulative rainfall over time.

The rainfall estimation from satellite can be classified according to instruments on board satellites. There are single and combined instruments. The single instrument includes microwave (MW) and Visible/InfraRed techniques. The latter were the first to be conceived and are rather simple to apply while at the same time they show a relatively low degree of accuracy. The combined instruments were developed from the existing VIS/IR techniques in combination with passive MW, with precipitation measuring instruments from space such as Precipitation Radar – PR [11].

The VIS and IR techniques use cloud radiative properties at VIS, NIR and IR wavelengths. These techniques can be divided into the following categories: cloud indexing, bispectral, life history and cloud model-based [12]. Each of the categories stresses a particular aspect of the sensing of cloud physics properties using satellite imagery [13]. Cloud indexing techniques assign a rain rate level to each cloud type identified in the satellite imagery. The simplest and perhaps most widely used is based on a high correlation between radar-estimated precipitation and fraction of the area colder than 235° K in the IR on Geostationary Operational Environmental Satellite-GOES imagery. The scheme, named GOES Precipitation Index (GPI), assigns these areas a constant rain rate of 3 mm/h, which is appropriate for tropical

Table 5 Land use Data in Blue Nile Basin

Code number	% in Basin	Type of land use
2	3.23×10^{-4}	Atlantic coast Dry Forest
59	5.15	Annual Grass and Sahel Shrub
63	0.66	Desert/Hammads/Shrubland
65	0.14	Shrubland with grass land
70	6.79×10^{-3}	Bushland and thicket
73	2.26×10^{-3}	Sudanian woodland with crops
74	2.59×10^{-3}	Atlantic evergreen broadleaf
93	1.32	Grassland/Sudanian woodland
94	1.51	Sudanian woodland/Savanna
95	0.15	Savanna
120	4.93	Semi-desert grassland with shrubland
121	0.62	Grassland/Shrubland
122	3.06	Shrubland
127	0.02	Grassland with shrubland
129	3.24×10^{-4}	Grassland
140	9.06×10^{-3}	Cropland
141	6.476×10^{-4}	Cropland (Peanuts with Baobab/Acacia)
169	3.24×10^{-4}	Grassland/Cropland
170	0.19	Agricultural Mosaic
191	0.13	Barren or Sparsely vegetated
192	0.47	Sahara/Sahel Sparsely Vegetated
193	30.71	Barren Vegetated
194	38.71	N. Sahel Sparsely Vegetated
195	12.20	Sahara Hammadas

precipitation over $2.5° \times 2.5°$ areas. The GPI is a standard for climatologically rainfall analysis.

$$\text{Precipitation (mm)} = \text{FRAC} \times \text{RATE} \times \text{TIME}.$$

where FRAC is the fractional coverage of IR pixels colder than 235 K. RATE is 3 mm/hour. TIME is the number of hours over which “FRAC” was compiled.

Bispectral methods are based on the relationship between cold and bright clouds and high probability of precipitation, which is characteristic of cumulonimbus clouds. Lower probabilities are associated with cold but dull clouds (thin cirrus) or bright but warm (stratus). The algorithm is based on a supervised classification trained by radar to recognize precipitation from both VIS brightness and IR [14].

The life-history methods rely upon a detailed analysis of the cloud’s life cycle, which is particularly relevant for convective clouds. A major problem arises in the presence of cirrus anvils from neighboring clouds: they often screen the cloud life cycle underneath leading to possible underestimates early in the day and overestimates towards the evening.

The cloud model techniques aim at introducing the cloud physics into the retrieval process for a quantitative improvement derived from the overall better physical description of the rain formation processes.

4 Rain Gauge Distribution in the Basin

In the Blue Nile Basin, there is a permanent rain gauge network. This network consists of 35 stations and has a density of approximately 1 station per 10,000 km^2. This network is maintained by volunteers who report daily or monthly rainfall depth in mm. The network was set up to provide valuable information on the spatial structure of rainfall at short distances. In this chapter, the network is presented as shown in Fig. 6 and Table 6 show the location of all the rain gauges and its coordinates.

5 Combining Datasets, Data Analysis and Interpretation

The data and the source of each data that are required in order to apply for hydrological model are listed in Table 7.

In this chapter, there are five datasets of rainfall used:

1. Tropical Rainfall Measuring Mission (TRMM).
2. Global Satellite Mapping of Precipitation (GSMAP).
3. Global Precipitation Climatology Centre (GPCC).

Fig. 6 Rain gauges network in Blue Nile Basin

Table 6 Coordinates of rain gauges stations in Blue Nile Basin

No.	Latitude	Longitude	No.	Latitude	Longitude
1	32.65	15.68	18	36.54	11.38
2	33.41	15.84	19	33.95	10.88
3	34.33	14.61	20	35.51	9.9
4	34.37	15.37	21	35.93	10.41
5	32.66	14.49	22	39.18	10.95
6	36.24	14.23	23	39.66	10.3
7	32.54	14.04	24	37.85	10.32
8	33.19	12.84	25	36.97	9.24
9	36.95	13.29	26	34.38	10.15
10	34.14	13.87	27	34.15	9.48
11	35.05	14.06	28	34.84	8.48
12	36.06	13.14	29	35.55	7.55
13	35.81	12.37	30	34.46	12.69
14	33.18	11.48	31	35.1	11.44
15	38.63	11.45	32	37.95	11.98
16	39.38	11.72	33	35.98	8.58
17	35.63	11.04	34	32.94	15.01
			35	32.91	16.08

Table 7 Global dataset sources used in hydrological model

Type	Description	Source	Original spatial resolution	Remarks
Land use and soil data	Digital elevation model (DEM)	USGS-Hydro1K	1,000 m	Global data
	Soil map	FAO-DSMW	0.25°	Global data 2000
	Soil properties	FAO	–	USGS soil triangle
	Land cover type	GLCC	1,000 m	Global data April 1992 to March 1993
	NDVI	NOAA-AVHRR	8 km	Half monthly data, 1981–2007
Hydro-meteo-rological data	Precipitation (daily)	Ethiopian Meteo-rological System	Sparsely distributed	35 stations from 1971 to 1995
	Max and min temperature	GPCC – Global dataset	1°	Global, daily data from 1980 to 2007
	Observed dis-charge (Monthly)	Global river dis-charge database	Sparsely distributed	Khartoum station from 1976 to 1979
	Observed dis-charge (10 days)	Alexandria University	Sparsely distributed	Khartoum station from 1998 to 2002

4. Model for Interdisciplinary Research on Climate (MIROC3.2-hires).
5. Community Climate System Model, version 3.0 (CCSM3).

The data periods can be estimated based on available stream flow data. The ground stations set is comprised of 35 rain gauges distributed around the Blue Nile Basin with daily data. The temporal coverage is from 1971 to 1995.

The GPCC, CCSM3 and MIROC3.3-hires model dataset consists of 74 stations in the Blue Nile Basin of precipitation. These stations correspond to the spatial resolution of these datasets covered the study areas.

TRMM datasets have 220 stations for the Blue Nile Basin. These stations correspond to the spatial resolution of these datasets covered in the study areas.

GSMAP-MVK datasets have about 1,200 stations for Blue Nile Basin. Average accumulated rainfall time series dataset was calculated for each type of datasets. The period of interest is 2001 to 2002. The number of stations and their location are important as any hydrological model assigns climate inputs to each sub-basin in the model based on the closest station to the grid in each point [15].

5.1 TRMM-3B42-V7

The 3B42 precipitation dataset is one of the Tropical Rainfall Measuring Mission (TRMM) operational data products. It is produced by the TRMM Multi-satellite Precipitation Analysis (TMPA) scheme for combining precipitation estimates from multiple satellite, as well as land surface precipitation gauge analyses where feasible, at fine scales (0.25° × 0.25°), and daily. The precipitation-related passive microwave data are collected from LEO satellites instruments (SSM/I, TMI, AMSR-E, AMSU-B). A full description of this TRMM-3B42 product can be found in Huffman et al. [16]. Figure 7 shows the distribution of the available TRMM-3B42-V7 Rainfall data for the Blue Nile Basin.

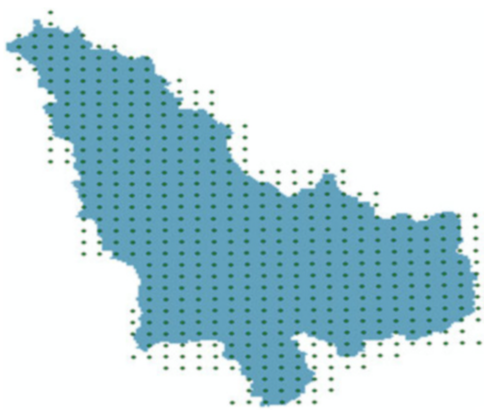

Fig. 7 Spatial distribution of TRMM-3B42-V7 rainfall observation points in the Blue Nile basin.

5.2 GSMAP-MVK

The Global Satellite Mapping of precipitation is a technique based upon passive microwave data from LEO satellite radiometers with cloud motion vectors and Kalman filtering inferred from geostationary IR images. The motion vectors are used to interpolate microwave rainfall estimates between LEO satellite microwaves radiometer overpasses.

The algorithm that produces the passive microwaves rain rates is described. The microwave data are obtained from six satellite radiometers: TRMM Microwave Imager (TMI) (on board TRMM), Advanced Microwave Scanning Radiometer (AMSR-E) (on board Aqua), AMSR (on board Advanced Earth Observing Satellite (ADEOS-II) and SSMI (on board Defence Meteorological Satellite Program (DMSP)-F13), F14 and F15). Unlike the case of the CMORPH technique, the IR brightness temperature is used to refine the rainfall estimates using the Kalman filter. A description of the GSMAP-MVK algorithm can be found in Ushio et al. [17]. The GAMAP-MVK precipitation product is available with different temporal resolutions (hourly, daily and monthly) at a grid resolution of 0.1°; the domains covered include the global latitude band 60°N-60°S, and the period of coverage is from January 2001 until the present. The data are accessible on the website of the Japan Aerospace Exploration (JAXA). Figure 8 shows the distribution of the available GAMAP-MVK Rainfall data in the Blue Nile Basin [18].

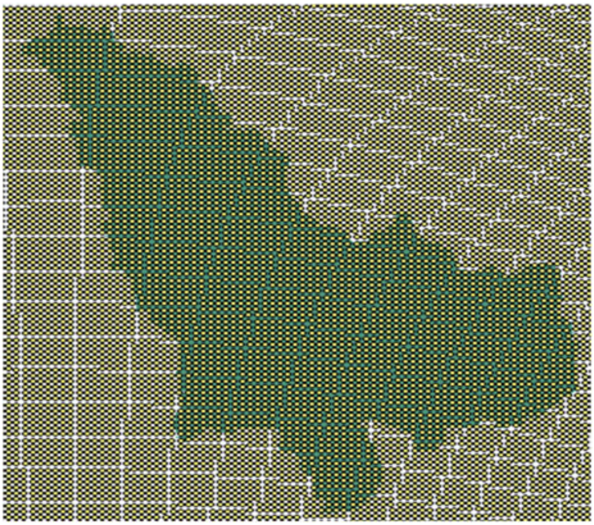

Fig. 8 Spatial distribution of GSMAP-MVK rainfall observation points in the Blue Nile Basin.

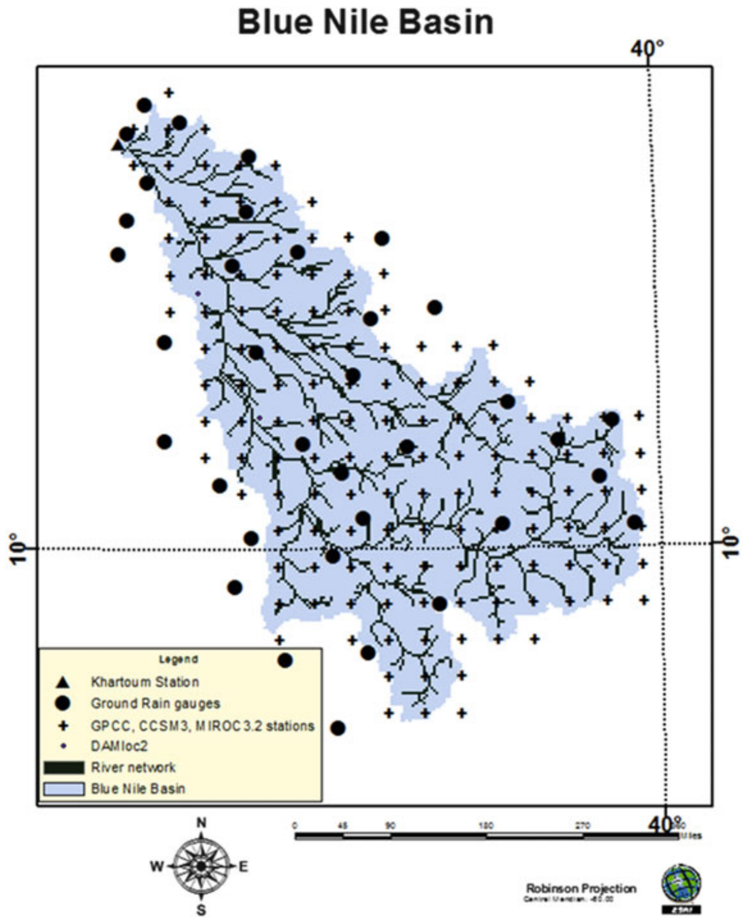

Fig. 9 Spatial distribution of rainfall observation points in the Blue Nile basin [19]

5.3 Future Precipitation Scenarios

Climate change projections were obtained from the Intergovernmental Panel on Climate Change as monthly means for two GCMs outputs, based on current climate, and a 30-year average (1961–1990) dataset (A1B emission scenario) (CRU-Climate Research Unit, East Anglia, UK).

The two GCMs outputs selected were NCAR CCSM (National Centre for Atmospheric Research, USAA) and MIROC (Centre for Climate Research, Japan). GCM model outputs, MIROC3.2 and CCSM3.0, were considered for future rainfall scenarios. Figure 9 shows the distribution of the available rainfall data. All of the collected meteorological data were adjusted to a 1-km resolution for the computation units. The Thiessen polygon method was used to determine the distance between each pair of rain gauge points, in particular, for interpolating the rain gauge data [20].

5.4 Justification of GCMs Outputs

Daily future surface precipitation determined by these introduced GCMs was corrected against the 0.5^0 global daily meteorological dataset GPCC. The daily precipitation was corrected by employing the ratio of the H08 and GCM precipitation intensities in eight different classes (1, 5, 10, 15, 20, 25 and 30% largest daily intensities and the remaining samples) for 1961–2000. The wet day percentage in each GPCC grid for 1961–2000 was scales by the ratio of the GCMs' wet day percentage for 1961–2000 and five 20-year future periods (2001–2020, 2021–2040, 2041–2060, 2061–2080 and 2081–2100). Each future climate prediction obtained by GCM simulation did not necessarily show similar characteristics to the conditions of the observed short time-scale climate. This was because scenario simulations by GCMs reflect their own internal climate systems, resulting from differences in SST time series, monsoon activity and other seasonal to annual climate oscillations.

6 Analysis and Assessment of Precipitation Data

In this section, Global Satellite Precipitation datasets and GCM outputs from 2001 to 2004 were evaluated using ground station precipitation and GPCC dataset. No attempt was made to interpolate data in order to improve spatial resolution except the estimation of areal precipitation of the study areas.

6.1 Rainfall Data Analysis

A comparison of precipitation datasets used is needed to understand model behaviour and help in calibration processes as they come from different sources with different measuring systems and estimation algorithms.

The comparison of estimation methods requires the definition of a set of reference values of error criteria in order to evaluate the agreement between the estimates and the reference values. The reference dataset was average rain gauge data and GPCC dataset after its evaluation. Moreover, remote sensed data and global data are space-average rainfall values, while ground stations measurements are point rainfall. The areal rainfall was estimated for the entire watershed for all datasets using Thiessen polygon method.

The rainfall comparison was done both using visually analysis and statistical criteria. Daily, monthly and annual average rainfall of global data and rain gauge were plotted together. Simple statistical tests were performed on time series such as standard error, absolute error and correlation coefficient.

Although rain gauge observations provide longer records [21], they do not provide a reliable spatial representation. For example, the distribution of gauge networks is sparse in desert and mountainous areas. Remote sensing techniques, such as those using radar or satellites, are useful for monitoring rainfall over large mountainous and arid regions. In addition, time series accuracy and precision being potentially locally be lower than existing and corresponding datasets derived from ground-based measurements, they provide more homogeneous data quality compared ground observations. Satellite-based datasets need to be examined and verified by comparison with ground-based rain gauge data. In this chapter, the comparison has been done between GPCC dataset and Ground data. GPCC datasets were considered as reference data to evaluate the other global satellite data.

6.2 Results of Comparison Between Ground Data and GPCC Datasets

6.2.1 Temporal Comparison

For ground reference data, an available grid analysis of the gauge dataset produced by the Global Precipitation Climatology Centre (GPCC) was used. The GPCC dataset showed strong correlation with individual gauge measurements accessed from the Nile Basin Capacity Building Network for River Engineering for the study period 1991–1994. There were around 60–70 gauge reports prepared daily in GPCC for our study period. To assess the uncertainties in the reference data, the GPCC monthly rainfall dataset was compared to monthly rainfall ground data, expressed as mean real precipitation (mm/month) (Fig. 10). Although high levels of precipitation appeared to be somewhat underestimated, the GPCC dataset appeared to correctly capture the seasonality of the precipitation. Difference between the

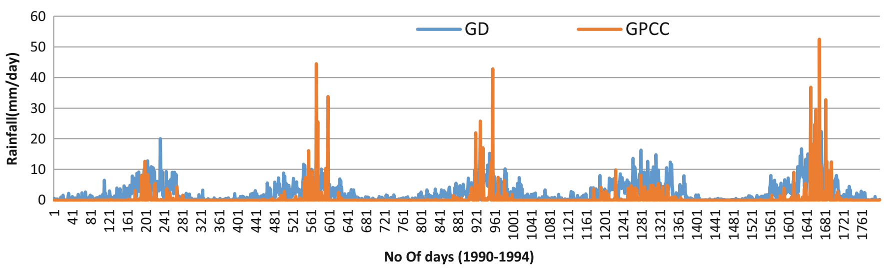

Fig. 10 Comparisons between GD and GPCC Precipitation Monthly Data (Blue Nile)

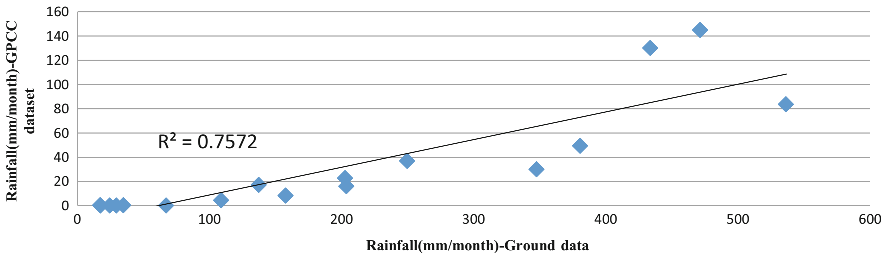

Fig. 11 Comparisons between GD and GPCC Precipitation Monthly Data (B.N Basin)

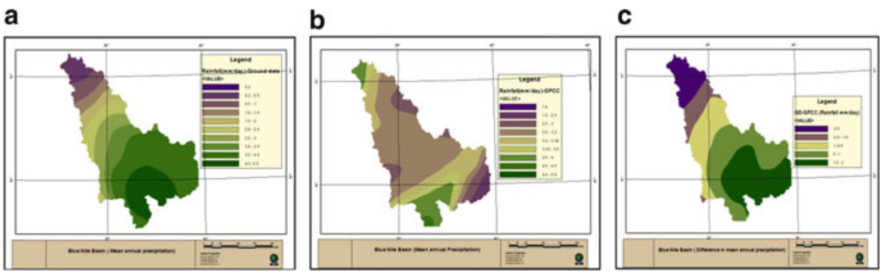

Fig. 12 Comparison of mean annual precipitation in GD and GPCC data for the time period 1990–1994 (**a**) GD (mm/day)-BN, (**b**) GPCC (mm/day)-BN, (**c**) Difference in mean annual precipitation between GD and GPCC (mm/day)-BN

observed data and the GPCC dataset is presented in Fig. 11 for the Blue Nile Basin. The correlation coefficient between the two groups was 0.763 in the Blue Nile Basin. Consequently, the results confirm that there was no substantial error in the GPCC dataset. Therefore, the GPCC dataset can be used as a reference dataset for the Blue Nile Basin.

6.2.2 Spatial Comparison

(a) Spatial distribution of annual average rainfall

Figure 12 shows mean annual precipitation in a 1° grid for the 5 years from 1990 to 1994. There is good accordance in the precipitation pattern. The maximum mean annual rainfall in the ground-based rainfall data is 5.5 mm/day in the Blue Nile Basin (Fig. 12a) and for GPCC dataset is 5.0 mm/day in Blue Nile Basin (Fig. 12b). GPCC overestimates precipitation along the Blue Nile Basin by a maximum of 1.0 mm/day (Fig. 12c).

(b) Spatial distribution of mean flood season rainfall

Because the area of Blue Nile Basin receives rainfall during months (July–August–September), we selected this as flood season rainfall distribution to compare to ground data.

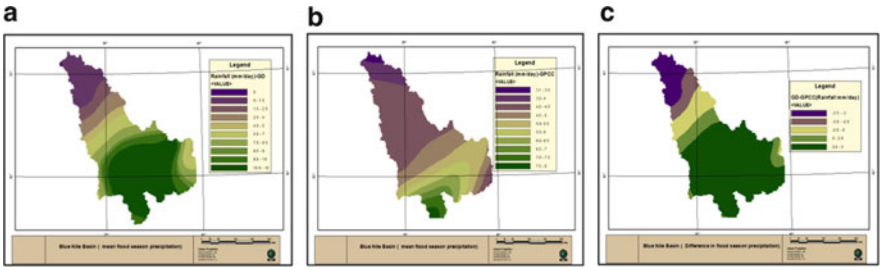

Fig. 13 Comparison of mean flood season precipitation in GD and GPCC data for the time period 1990–1994. (**a**) GD (mm/day)-BN, (**b**) GPCC (mm/day)-BN, (**c**) Difference in mean annual precipitation between GD and GPCC (mm/day)-BN

Comparison of mean flood season precipitation ground data (sparsely distribution) and the GPCC dataset (1° × 1°) for the 1990–1994 period is shown in Fig. 13. Maximum mean flood season precipitation in Ground data is 12 mm/day for Blue Nile Basin (Fig. 13a) and for the GPCC dataset is 8.0 mm/day (Fig. 13b). GPCC dataset underestimates rainfall in the south part of the Blue Nile Basin compared with ground data. But, GPCC dataset overestimates rainfall in the north part of the Blue Nile Basin with a maximum overestimation of 3.0 mm/day (Fig. 13c).

6.2.3 Inter-Annual Comparison

Figure 13 shows a comparison between time series of monthly areal precipitation average over Blue Nile Basin in ground data and GPCC dataset from 1991 to 1994. The fluctuation in variations in ground data and the GPCC dataset are in good accordance with each other. Maximum precipitation occurs in the flood season, and minimum rainfall occurs in the dry season (Jan–May) in both the ground data and the GPCC dataset. Comparison of areal rainfall average shows that GPCC underestimates rainfall compared with ground data;

7 Results and Discussion

7.1 TRMM Satellite Data (TRM'M_3B42_V7)

7.1.1 Temporal Comparison

The TRMM_3B42 precipitation output comprises 0.25° × 0.25° grid cells for every 3 h, with spatial extent covering a global belt (−180°W to 180°E) extending from 50°S to 50°N latitude. In this research, we used TRMM_3B42_V7 data covering the Blue Nile Basin in Ethiopia and Sudan from 2001 to 2004. The TRMM data shows both overestimation of precipitation during the simulation period especially

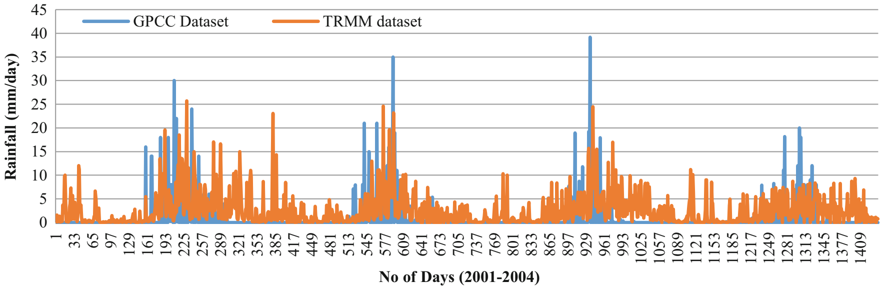

Fig. 14 Comparisons between GPCC and TRMM-3B42 Precipitation Daily Data (Blue Nile)

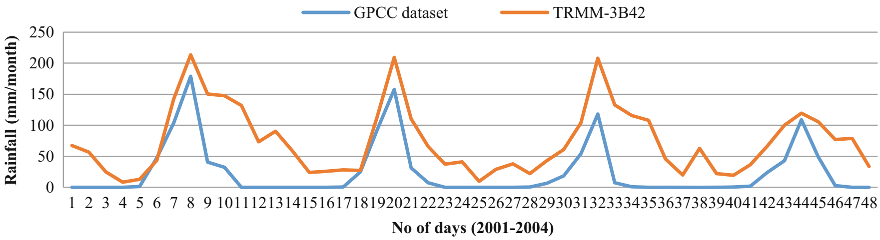

Fig. 15 Comparisons between GPCC and TRMM-3B42 Precipitation Monthly Data (BN Basin)

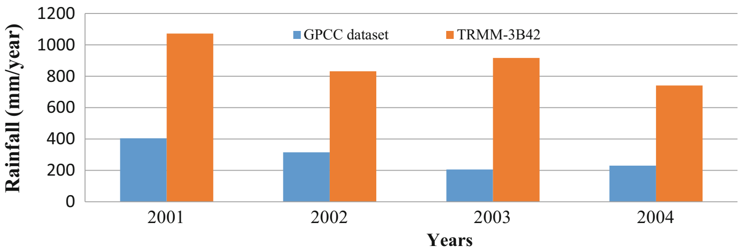

Fig. 16 Comparisons between GPCC and TRMM-3B42 Precipitation Annual Data (BN Basin)

in the dry season (Fig. 14). Overestimation is appeared in daily, monthly and annual simulation (Fig. 15). However, the seasonal precipitation trend is nearly the same for TRMM and GPCC dataset (Fig. 16); dry and wet months of the global data correspond to that of GPCC dataset. Consequently, TRMM-3B42 dataset is good at predicting flood and dry seasons in the Blue Nile Basin.

Differences between the TRMM dataset and the GPCC dataset are presented in Fig. 17 for the Blue Nile Basin. The correlation coefficient between the two groups was 0.6. Consequently, the results confirm that there were some errors in TRMM dataset to be used in these basins but it is good for predicting the peak flow and the flood season.

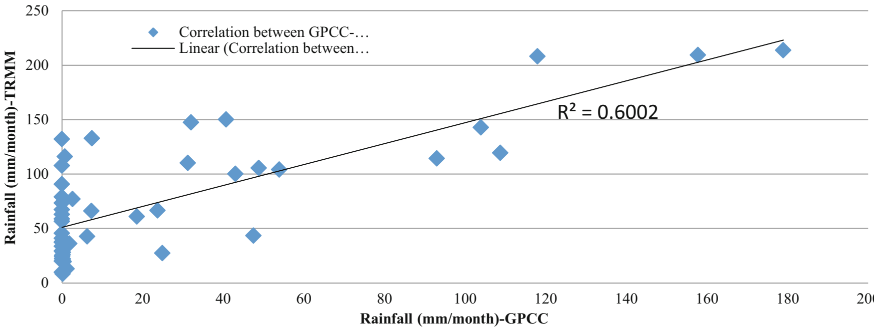

Fig. 17 Comparisons between GPCC and TRMM Precipitation Monthly Data (B.N Basin)

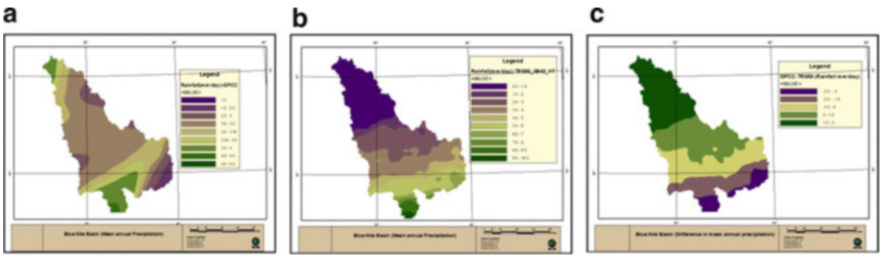

Fig. 18 Comparisons of mean annual precipitation in GPCC and TRMM data for the time period 2001–2004. (**a**) GPCC (mm/day)-BN, (**b**) TRMM (mm/day)-BN, (**c**) Difference in mean annual precipitation between GPCC and TRMM (mm/day)-BN

7.1.2 Spatial Comparison

Figure 18(a–c) shows mean annual precipitation in a 0.25° grid for the 4 years from 2001 to 2004 for the GPCC data and TRMM dataset. There is good agreement in precipitation pattern for the Blue Nile Basin. The maximum mean annual rainfall in the GPCC data is 8.0 mm/day and for the TRMM dataset is 10.5 mm/day. The TRMM dataset overestimates precipitation along the southern part of Blue Nile Basin by a maximum of 3.0 mm/day. On the other hand, the TRMM dataset underestimates precipitation along the northern part of Blue Nile Basin by a maximum 3 mm/day.

7.2 GSMAP_MVK Global Satellite Data

7.2.1 Temporal Comparison

In this section, we used the GSMAP's surface rainfall product currently known as "GSMAP_MVK+ version 4.8.4." Among the several GSMap versions currently

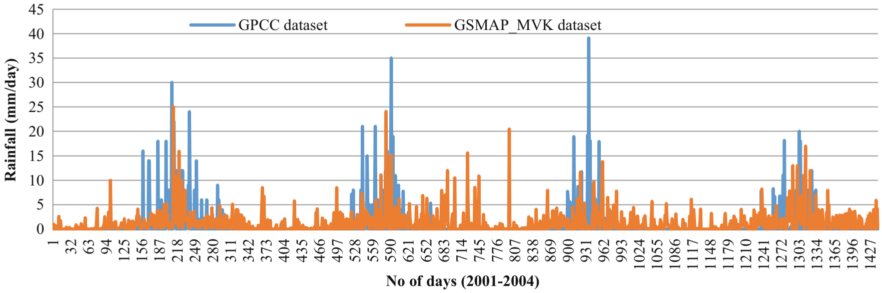

Fig. 19 Comparisons between GPCC and GSMAP_MVK Precipitation Daily Data (Blue Nile)

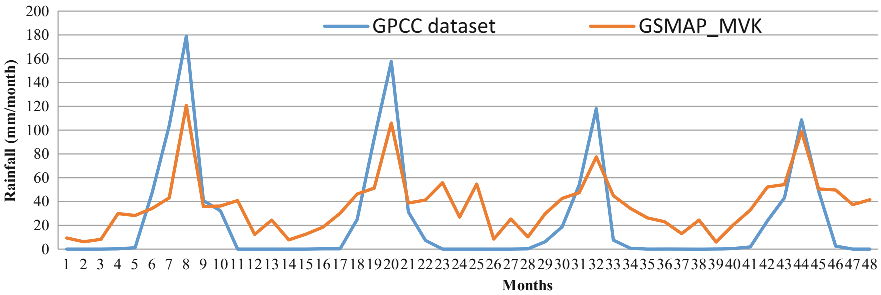

Fig. 20 Comparisons between GPCC and GSMAP_MVK Precipitation Monthly Data (Blue Nile)

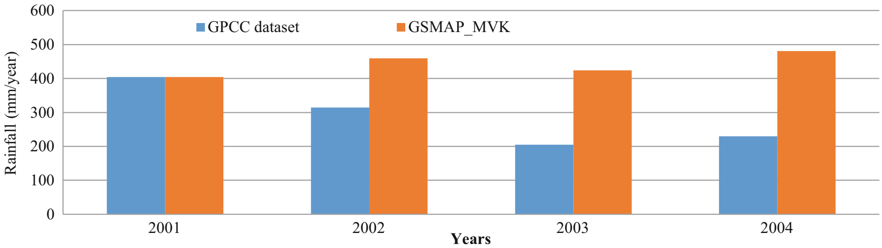

Fig. 21 Comparisons between GPCC and GSMAP_MVK Annual Precipitation Data (Blue Nile)

available ground gauge correction is applied to this GSMaP product. The product's highest space and time resolutions are 0.1° and 1 h, respectively. We chose a 4-year period from 2001 to 2004 for this study, and all the datasets were evaluated at 0.1° resolution with daily accumulation.

The GSMAP-MVK+ dataset has considerably underestimated the precipitation in the flood season and overestimated in the dry season related to GPCC dataset (Figs. 19, 20, and 21). For instance, in 2001, 2002 and 2003, the underestimation in the peak flow reached approximately 65%. The monthly rainfall variation is the same except in January and February but still the overestimation is for the dry season. One of the reasons is related to the data spatial resolution which is poor with

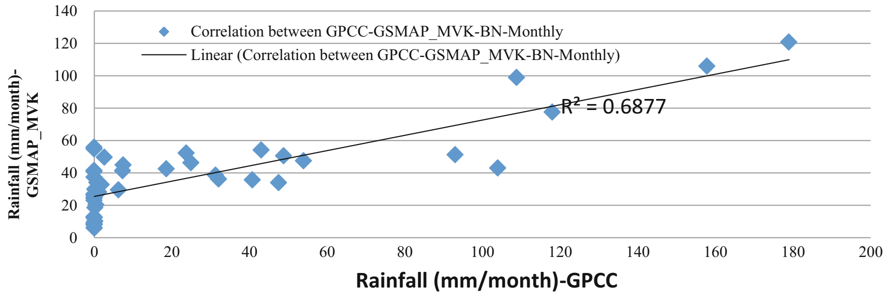

Fig. 22 Comparisons between GPCC and GSMAP_MVK Precipitation Monthly Data (B.N Basin)

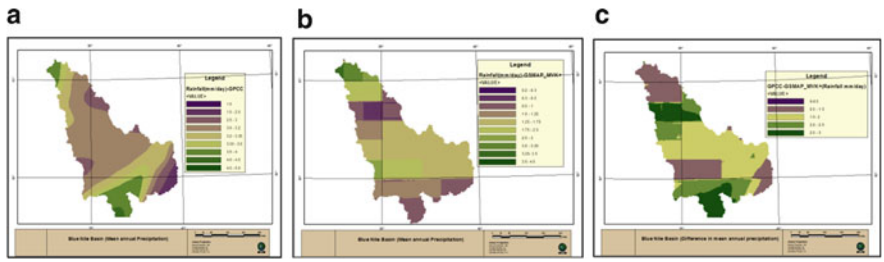

Fig. 23 Comparison of mean annual precipitation in GPCC and GSMAP_MVK data for the time period 2001–2004. (**a**) GPCC (mm/day)-BN, (**b**) GSMAP_MVK (mm/day)-BN, (**c**) Difference in mean annual precipitation between GPCC and GSMAP_MVK (mm/day)-BN

more void value data. This data can be improved by spatial interpolation or by infilling with other data from the nearest stations. In this way, the seasonal variation is preserved and also modifications of the rainfall data of GSMAP_MVK dataset are possible.

Differences between the GSMAP_MVK dataset and the GPCC dataset are presented in Fig. 22. The correlation coefficient between the two groups was 0.687. Consequently, the results confirm that the GSMAP_MVK dataset is better than the TRMM-3B42 dataset. It can be improved more by infilling the no value or void data.

7.2.2 Spatial Comparison

Figure 23 shows mean annual precipitation in a 0.1° grid for the 4 years from 2001 to 2004 for the GPCC data and the GSMAP_MVK+ dataset. There is good agreement in the precipitation pattern (Fig. 23 a–c). The maximum mean annual rainfall in the GPCC data is 8.0 mm/day and for the GSMAP_MVK+ dataset is 4.5 mm/day. The GSMAP_MVK+ dataset underestimates precipitation along the Blue Nile Basin by a maximum of 2.5 mm/day.

7.3 *Improvement of GSMAP_MVK Precipitation Data*

7.3.1 Temporal Comparison

Correlation coefficient R^2 indicates the performance of the precipitation dataset TRMM_3B42_V7 and GSMAP_MVK+, from 2001 to 2004. The rainfall estimated using the GSMAP_MVK+ precipitation data is underestimated in the flood season. The rainfall estimated using the TRMM_3B43_V7 data, on the other hand, produces high estimation in the dry season and flood season. The underestimation estimated by the GSMAP_MVK+ data is mainly due to the large quantity of no values or missing data in the study area. For this reason, a combination of the GSMAP_MVK+ datasets and TRMM data is needed to replace these data with TRMM data. We refer to the GSMAP_MVK+ datasets that are improved in this way as GSMAP_MVK_T. Figures 24, 25 and 26 show the daily, monthly and annual precipitation using the new product for the Blue Nile Basin and the Atbara

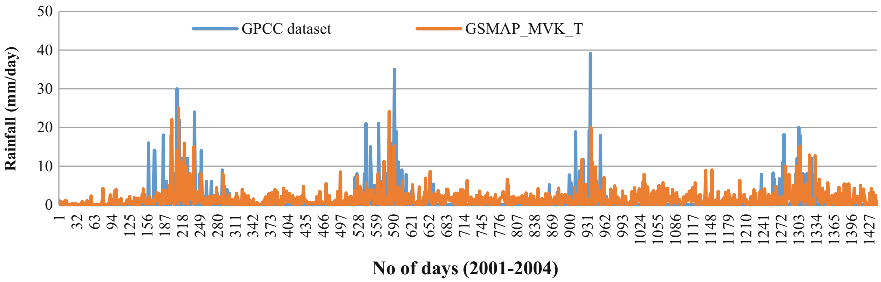

Fig. 24 Comparisons between GPCC and GSMAP_MVK_T Precipitation Daily Data (Blue Nile)

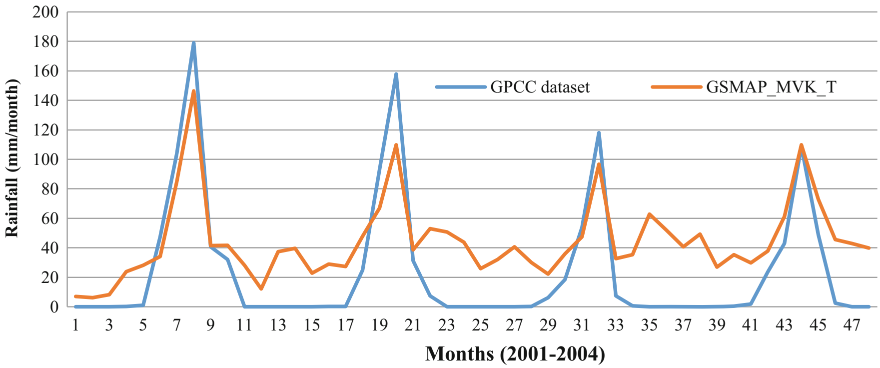

Fig. 25 Comparisons between GPCC and GSMAP_MVK_T Precipitation Monthly Data (Blue Nile)

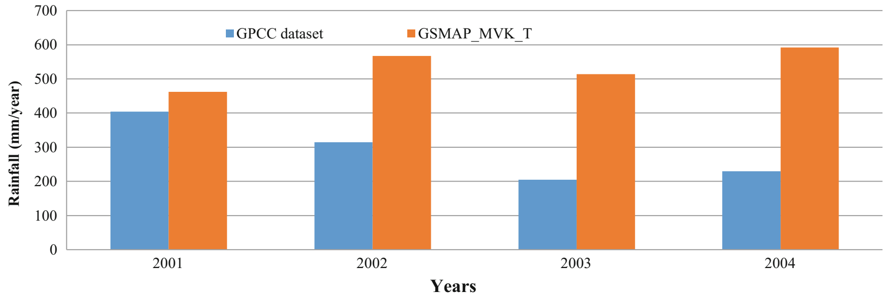

Fig. 26 Comparisons between GPCC and GSMAP_MVK_T Precipitation Annual Data (Blue Nile)

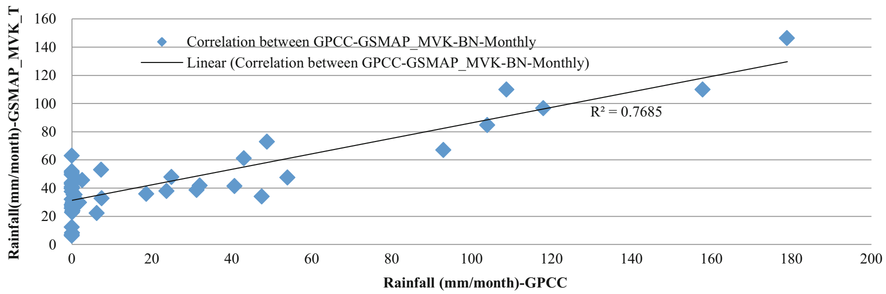

Fig. 27 Comparisons between GPCC and GSMAP_MVK_T Precipitation Monthly Data

Basin. As a result, the correlation coefficient for precipitation estimated using GSMAP_MVK_T became better than the coefficient that was estimated using TRMM_3B42_V7 and using GSMAP_MVK+ only. The correlation coefficient became 0.768 as shown in Fig. 27.

7.3.2 Spatial Comparison

Figure 28(a–c) shows mean annual precipitation in a 0.1° grid for the 4 years from 2001 to 2004 for the GPCC data and the GSMAP_MVK_T dataset. There is better agreement in the precipitation pattern than the previous patterns using TRMM data and GSMAP_MVK+ alone. The maximum mean annual rainfall in the GPCC data is 8.0 mm/day and for the GSMAP_MVK_T dataset is 5.5 mm/day. The GSMAP_MVK_T dataset underestimates precipitation well along the Blue Nile Basin by maximum of 1.5 mm/day.

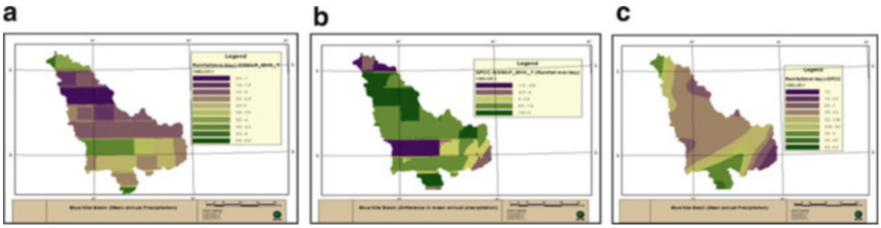

Fig. 28 Comparison of mean annual precipitation in GPCC and GSMAP_MVK_T data for the time period 2001–2004. (**a**) GPCC (mm/day)-BN, (**b**) GSMAP_MVK_T (mm/day)-BN, (**c**) Difference in mean annual precipitation between GPCC and GSMAP_MVK_T (mm/day)-BN

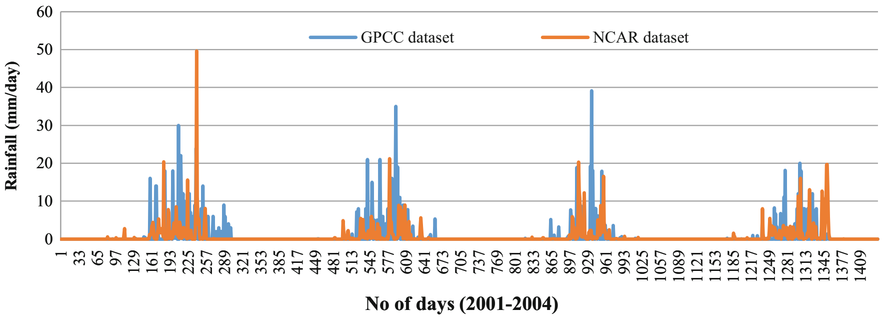

Fig. 29 Comparisons between GPCC and NCAR_CCSM3 Precipitation Daily Data (Blue Nile)

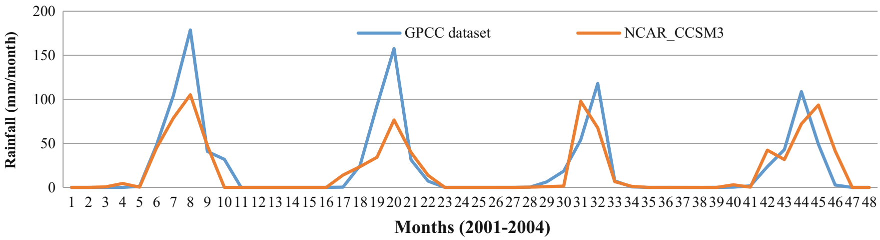

Fig. 30 Comparisons between GPCC and NCAR_CCSM3 Precipitation Monthly Data (Blue Nile)

7.4 Results of Comparisons Between GPCC Datasets and GCMs Outputs

7.4.1 CCSM3_NCAR Global Data

(a) Inter-annual Comparison

The CCSM3_NCAR dataset has considerably underestimated the precipitation in the Blue Nile Basin related to GPCC dataset (Figs. 29, 30, and 31). For instance,

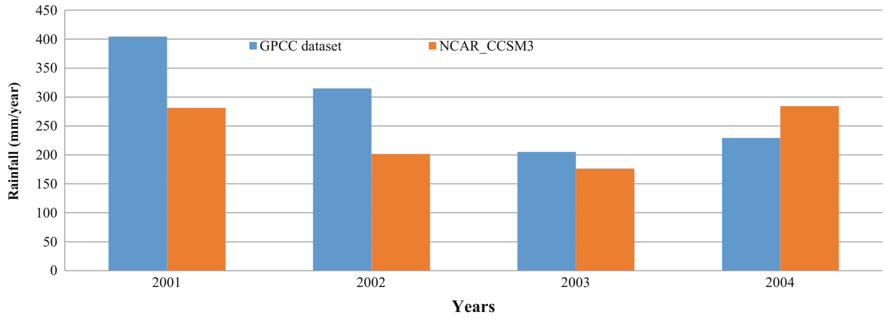

Fig. 31 Comparisons between GPCC and NCAR_CCSM3 Precipitation Annual Data (Blue Nile)

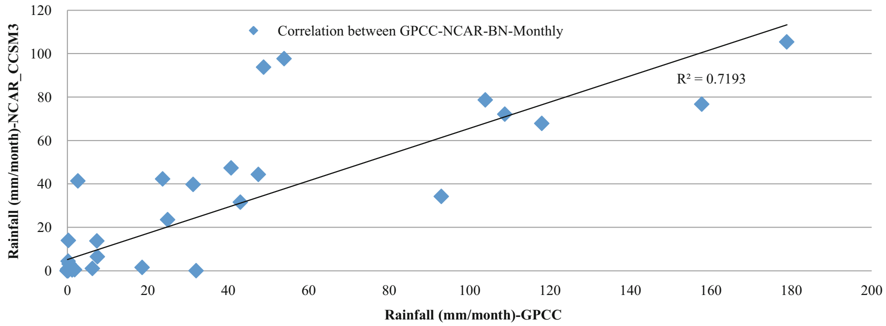

Fig. 32 Comparisons between GPCC and NCAR_CCSM3 Precipitation Monthly Data

in 2001, and 2002, the underestimation in the peak flow reached approximately 60% in Blue Nile Basin. The monthly rainfall variation is as same as the trend in GPCC data all the year. Differences between the CCSM3_NCAR dataset and the GPCC dataset are presented in Fig. 32. The correlation coefficient between the two groups was 0.719. Consequently, the results confirm that CCSM3_NCAR dataset can be used for flood prediction in Blue Nile Basin.

(b) Spatial Comparison

Figure 33(a–c) shows mean annual precipitation in a 1.0° grid for the 4 years from 2001 to 2004 for GPCC data and CCSM3_NCAR dataset. There is a good accordance in precipitation pattern related to GPCC as reference data. The maximum mean annual rainfall in GPCC data is 8.0 mm/day and for CCSM3_NCAR dataset is 1.5 mm/day. CCSM3_NCAR dataset underestimates precipitation nearly along the Blue Nile Basin by a maximum of 3.0 mm/day.

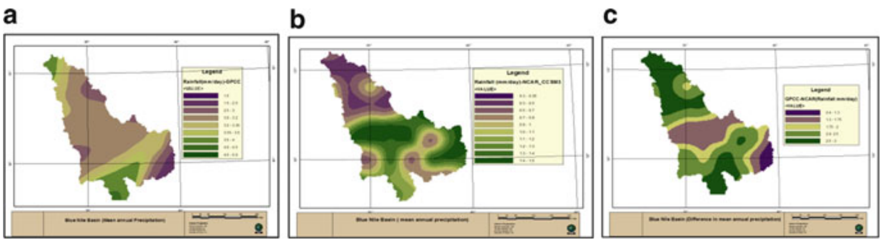

Fig. 33 Comparisons of mean annual precipitation in GPCC and NCAR_CCSM3 data for the time period 2001–2004. (**a**) GPCC (mm/day)-BN, (**b**) NCAR_CCSM3 (mm/day)-BN, (**c**) Difference in mean annual precipitation between GPCC and NCAR_CCSM3 (mm/day)-BN

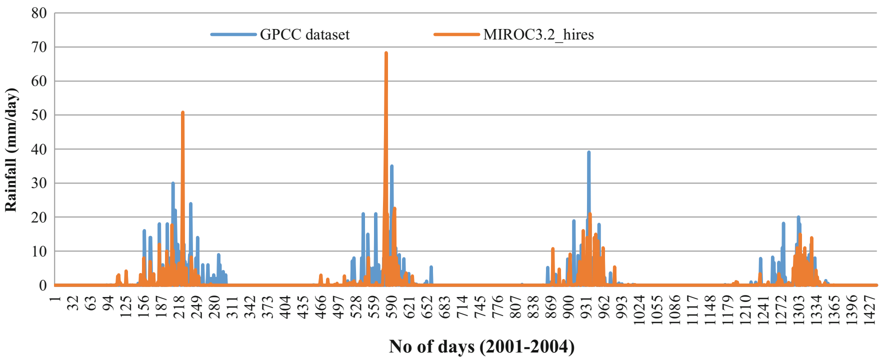

Fig. 34 Comparisons between GPCC and MIROC3.2 Precipitation Daily Data (Blue Nile)

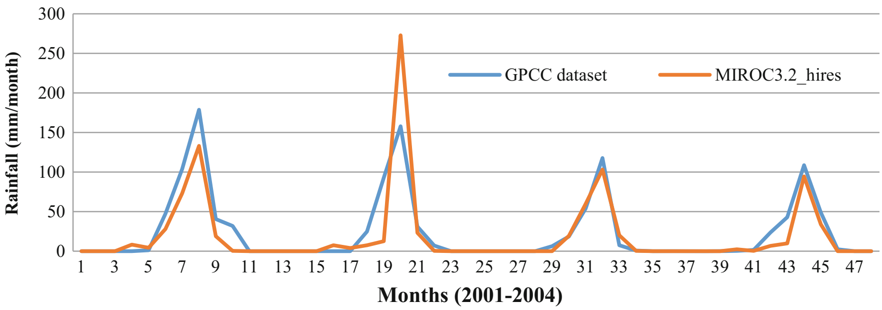

Fig. 35 Comparisons between GPCC and MIROC3.2 Precipitation Monthly Data (Blue Nile)

7.4.2 MIROC3.2_hires Global Data

(a) Inter-annual Comparison

The MIROC3.2_hires dataset provides a good estimation for the precipitation in the Blue Nile Basin related to the GPCC dataset (Figs. 34, 35, and 36). For instance,

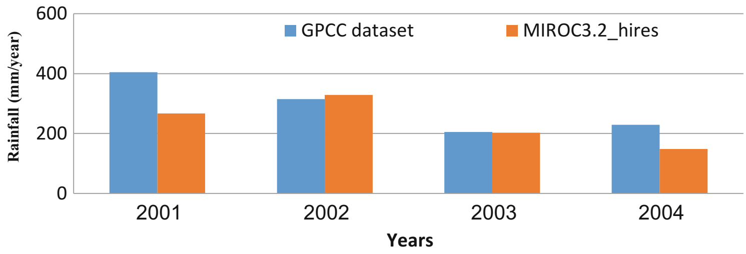

Fig. 36 Comparisons between GPCC and MIROC3.2 Precipitation Annual Data (Blue Nile)

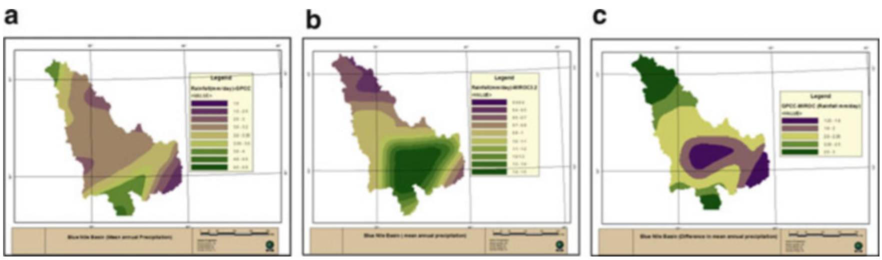

Fig. 37 Comparisons of mean annual precipitation in GPCC and MIROC3.2 data for the time period 2001–2004 (**a**) GPCC (mm/day)-BN, (**b**) MIROC3.2 (mm/day)-BN, (**c**) Difference in mean annual precipitation between GPCC and MIROC3.2 (mm/day)-BN

in 2003, and 2004, the peak flows are the same for two basins. The monthly rainfall variation is the same as the trend in the GPCC data for the whole year. The correlation coefficient between the two groups was 0.753. Consequently, the results confirm that MIROC3.2_hires dataset can be used for flood prediction in the Blue Nile Basin.

(b) Spatial Comparison

Figure 37(a–c) shows mean annual precipitation in a 1.0° grid for the 4 years from 2001 to 2004 for GPCC data and MIROC3.2_hires datasets. There is a good accordance in precipitation pattern related to GPCC as the reference data. The maximum mean annual rainfall in GPCC data is 8.0 mm/day and for MIROC3.2_hires dataset is 1.5 mm/day. MIROC3.2_hires dataset underestimates precipitation along the Blue Nile Basin by maximum of 3.0 mm/day.

7.5 Rainfall Estimation Error

The visual interpretation of global data was complemented by statistical analysis. Error (residual) and absolute error between global datasets and rain gauge-based precipitation data for simulation period were calculated [22]. We considered rain

Table 8 Statistical analysis of GPCC dataset (mm/day)-Blue Nile Basin

	GD	GPCC	Error	Absolute error
Mean	0.938	0.240	0.914	0.944
Maximum	22.4	52.5	20	49.2
Minimum	0	0	−4.92	0
Median	0.907	0	0.719	0.846
Standard deviation	2.95	3.02	3.67	3.53

Table 9 Statistical analysis of TRMM dataset – Blue Nile Basin

	GPCC	TRMM	Error	Absolute error
Mean	0.801	2.47	−1.67	2.64
Maximum	39.1	25.7	38.1	38.1
Minimum	0	0	−25.4	0
Median	0	1.16	−0.85	1.18
Standard deviation	3.29	3.42	4.42	3.88

Table 10 Statistical analysis of GSMAP_MVK dataset – Blue Nile Basin

	GPCC	GSMAP_MVK	Error	Absolute error
Mean	0.801	1.23	−0.428	1.64
Maximum	39.1	25.0	39	39
Minimum	0	0	−24.1	0
Median	0	0.404	−0.249	0.481
Standard deviation	3.29	2.32	3.69	3.31

Table 11 Statistical analysis of GSMAP_MVK_T dataset – Blue Nile Basin

	GPCC	GSMAP_MVK_T	Error	Absolute error
Mean	0.801	1.147	−0.682	1.85
Maximum	39.1	25.0	39	39
Minimum	0	0	−24.1	0
Median	0	0.8	−0.642	0.901
Standard deviation	3.29	2.36	3.69	3.23

gauge-based data values $Z(t)$, and estimate value data as $\hat{z}(t)$.The error is calculated as $e(t) = z(t) - \hat{z}(t)$ and the absolute errors is $|e(t)|$. For each of these quantities, the minimum, the maximum, the mean, the median and the standard deviation were computed. The results are presented in Tables 8, 9, 10 and 11. In general, the dataset deviation of rain gauge and GPCC are closer. In addition, minimum and maximum errors are also closer.

The TRMM global dataset overestimated precipitation. TRMM mean precipitation is almost 50% over of GPCC precipitation during the flood season in the Blue Nile Basin.

Tables show that GSMAP_MVK mean precipitation is almost 50% less than ground station base precipitation. On the other hand, GSMAP_MVK_T mean precipitation is almost 30% less than ground station-based precipitation which is better than GSMAP-MVK.

8 Conclusions and Recommendations

8.1 Conclusions

(a) The Blue Nile Basin and Atbara basins exhibit variability in topography, climate and geomorphology in its different sub-basins, lakes and wetlands, have an important role in hydrology of the basin.
(b) Ground stations data was not available during the calibration and validation period. The Global GPCC Rainfall ground-based data were used as a benchmark for other data.
(c) The GSMAP_MVK rainfall dataset underestimates considerably annual precipitation and seasonal precipitation as well. The main reason is that there are many no value or missing data in the study area. Therefore using them in model could not give good performance. Therefore, GSMAP-MVK modified to be GSMAP-MWR-T gave a good estimation for runoff in the Blue Nile Basin by substituting no value data with TRMM data.
(d) A combination of GSMAP_MVK and TRMM produced a modified dataset (GSMAP_MVK_T). In this way, the patterns of the variations in discharge could be simulated using TRMM datasets or GSMAP_MVK_T datasets.
(e) GSMAP_MVK_T performance is comparable to other satellite-based products, with slightly better probability of detection during the flood season, and the different satellite-based estimates as a group have better agreement among themselves during flood season than dry season.

8.2 Recommendations

(a) There are available remote available remote sensed data for long temporal coverage that could be used for hydrologic modelling purpose. Remote sensed data or global data can be used to complement local data, in order to perform hydrologic analysis for longer period than available local data. A study should be carried out to see how these data can be adjusted to local conditions.
(b) Ground validation of remote sensed data is necessary in order to ensure a good quality of climate data. The ground validation would involve development of algorithms that would appropriate to local conditions that will improve the quality of rainfall estimation.

(c) It is necessary to define a way that remote sensed data would be integrated to local data so that the use a combination of local and satellite data could lead to good results.

References

1. Bardossy A, Das T (2006) Influence of rainfall observation network on model calibration and application. Hydrol Earth Syst Sci Discuss 3:3691–3726
2. Levizzani V, Amorati R, Meneguzzo F (2002) A review of satellite-based rainfall estimation methods. Consiglio Nazionale delle Ricerche, Istituto di Scienze dell'Atmosfera e del Clima, Bologna, Italy
3. Kawanishi T, Kuroiwa H, Kojima M, Oikawa K, Kozu T (2000) TRMM precipitation radar. Adv Space Res 25(5):969–972
4. Saavedra O, Yoshimura C, Negm A, Nadaoka K, Kanae S, Tri Phong V, Phu L, Toan Q, Ragab O, Suif Z, Hak D, El-Adawy A, Masria A, El-Tarabily A (2015) A platform for integrated water resources management for mega deltas under climate change. JSPS Mega Delta Project, IWTC
5. IPCC (Intergovernmental Panel on Climate Change) 2008: Climate change 2008: Synthesis Report. Contribution of working Group I, II and III to the Fourth Assessment Report
6. Conway D, Hulme M (1996) The impact of climate variability and climate change in the Nile Basin on future water resources in Egypt. Water Resour Dev 12(3):277–296
7. Pfafstetter O 1989 Classification of hydrographic basins Coding methodology
8. Arnold JG, Neitsch SL, Kiniry JR, Williams JR, King KW (2002) Soil and water assessment tool, theoretical documentation, Grassland, soil and water research laboratory—Agricultural Research Service. US, Texas
9. Ragab O (2014) Flood forecasting in Blue Nile basin using a process-based hydrological model. Int J Environ ISSN 2091–2854
10. Engman ET, Chouhan N (1995) Status of microwave soil moisture measurements with remote sensing. Remote Sens Environ 51:189–198
11. Hong Y, Alder RF, Hossain F, Curtis S, Huffman GJ (2007) Estimate gridded and time variant runoff curve numbers using satelliteremote sensing and geospatial data. Water Resour Res 43:285–294
12. Barrett EC, Martin DW (1981) The use of satellite data in rainfall monitoring. Academic Press, London, 340 pp
13. Kubota T et al. (2007) Global precipitation map using satelliteborne microwave radiometers by the GSMAP project: production and validation. IEEE Trans Geosci Remote Sens 45:2259–2275
14. Lakshmi V (2004) The role of satellite remote sensing in the prediction of ungauged basins. Hydrol Process 18:1029–1034
15. Easton ZM, Walter MT, Fuka DR, White ED, Steenhuis TS (2010) A simple concept for calibrating runoff thresholds in quasi-distributed variable source area watershed models. Process submitted, Hydrol
16. Huffman GJ, Adler RF, Bolvin DT, Gu G, Nelkin EJ, Bowman KP, Hong Y, Stocker EF, Wolff DB (2007) The TRMM multi-satellite precipitation analysis: Quasi-Global, Multi-Year, Combined-Sensor precipitation estimates at fine scale. J Hydrometeor 8(1):38–55
17. Ushio T, Kubota T, Shinge S, Okamoto K, Aonashi K, Inoue T, Takahashi N, Iguchi T, Kachi M, Oki R, Morimoto T, Kawasaki Z (2009) A kalman filter approach to the global satellite mapping of precipitation (GSMAP) from combined passive microwave and infrared data. J Meteor Soc Japan 87A:137–151

18. Ragab O, Ushio T (2012) Evaluation of GSMaP precipitation Estimates Over Blue Nile Basin, GPM and TRMM International Conference, at Tokyo, Japan
19. Ragab O (2011) Saavedra O. Simulation of Blue Nile River using a distributed hydrological model and Global Data Sets, ICWEE
20. Ragab O, Saavedra O, Hirabayashi Y (2013) Future variation in IVER discharge in the Atbara basin under climate change scenarios. Ann J Hydr Eng 57
21. Yatagai A, Arakawa O, Kamiguchi K, et al. (2009) A 44-year daily gridded precipitation dataset for Asia based on a dense network of rain ganges. SOLA 5:137–140. doi:10.2151/Sola.2009-035
22. Gregory JM (2002) Stouffer, Raper, Stott: an observationally based estimate of the climate sensitivity. J Climate 15(22):3117–3121
23. Barrett EC (1981) Satellite monitoring of extreme rainfall events in Satellite remote sensing. Applications to rural disasters Prof. joint ESA/FAO/WHO training Course, Rome, 1980, (European Space Agency, Paris, ESA – SP – 1035), pp 97–103

Recent Trends and Fluctuations of Rainfall in the Upper Blue Nile River Basin

Mosaad Khadr

Abstract During the last decades, water resource managers are facing severe challenges all over the world, and the trends of temperature and precipitation intensify this situation. Knowledge of the spatial variability and temporal trends of rainfall is essential for efficient management of water resource and agriculture. Rainfall plays a crucial role in the process because its variations, coupled with changes in extreme events, can influence water resources, on natural environments and human activities, as well as on human health and safety. In this chapter, an investigation of the rainfall variability of the Upper Blue Nile River Basin, the main source of the Nile River, was carried out by means of a daily rainfall data set of 22 meteorological stations with 48 years of observation. The nonparametric Mann–Kendall test and the Sen's slope estimator were used to identify the existence of trends and slope magnitude in rainfall at seasonal and annual scale. Results revealed that although there was a mix of positive and negative trends, they were statistically insignificant except at one station. In contrast, the trend and change point analyses of annual series found that 21 of the tested 22 rainfall stations did not show statistically significant changes. Furthermore, analyses of rainy seasonal series (June–September) showed significant changes only at 1 out of 22 stations. The spatial analysis of the trend in the Upper Blue Nile River Basin for several time scales showed that the negative trends are in western side and the positive trends are on the eastern side of the basin.

Keywords Blue Nile River Basin, Mann–Kendall test, Rainfall, Trend analysis

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M. Khadr (✉)
Faculty of Engineering, Tanta University, 31734 Tanta, Egypt
e-mail: mosaad.khadr@f-eng.tanta.edu.eg

A.M. Negm (ed.), *The Nile River*,
Hdb Env Chem (2017) 56: 451–466, DOI 10.1007/698_2017_1,

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1 Introduction

The Nile river, which is 6,650 km long, is the longest river in the world, 6,650 km in length. It travels from East and East-Central Africa to the Mediterranean Sea. Its watershed is in 11 countries as shown in Fig. 1 [1, 2]. The Nile Basin extends over 35 degrees of latitude, from the equatorial zone (4° S) to the northern subtropics (31° N) [3]. Significant increase in population and limited water resources make hydrological variations more critical [4]. The water demand in the Nile River Basin is increasing due to continual population growth leading to an increase in per capita water demand. Also, due to overpopulation and climate change negative impacts, stress on water resources in the basin is increasing. Therefore, understanding the historical, current, and projected hydrology of the Nile Basin is a must for managing the ever-increasing water demand within the basin. Understanding climate change and its impact on hydrological variability is important for water management and thus has received attention from researchers in different parts of the world (e.g., [3, 5–10]). Rainfall trends are often cited as one of the most important factors in explaining various socioeconomic problems such as food security. Changes in rainfall can be used to assess the influence of the climate system on hydrology. Some studies conducted recently to determine changes in hydrological variables include [10–14]. In Ethiopia, few studies analyzed the trend of hydroclimatic variables. Conway [15] reported declining annual rainfall over the Blue Nile and Atbara basins resulting in a reduction of river flows between 1945 and 1984. In contrast, recent investigations by Tesemma [16], Tekleab [8], and Gebremicael [17] agreed that rainfall over the Upper Blue Nile River Basin did not show a statistically significant trend for the last 40 years (1964–2005). In some parts of Ethiopia, such as northern Ethiopia, the high historical variability of rainfall and frequent drought conditions were identified [9, 17–20]. However, the few studies previously carried out in this region have reported inconsistent conclusions with regard to historical rainfall trends. For example, Conway [13] found no trends in long-term annual rainfall in the highlands of northeastern Ethiopia. Seleshi [18] reported no trend in annual and seasonal rainfall totals or a number of rainy days over the period

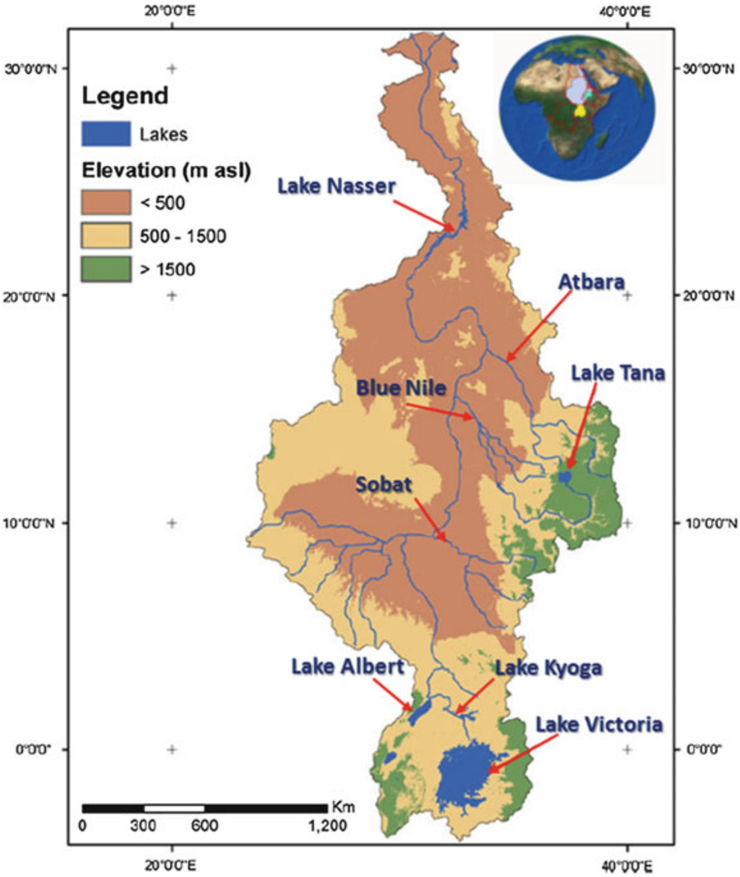

Fig. 1 Nile River Basin [18]

of 1965–2002 for the central, northern, and northwestern parts of the country but found a decline in rainfall totals in the eastern, southwestern, and southern parts of the nation. Cheung [21] detected a substantial decreasing rainfall trend in the central and southwestern parts of Ethiopia for the rainy season (June–September). However, no significant trend for extreme rainfall events at climate stations located in the northwestern highland parts of Ethiopia was detected [22, 23]. Over the past decades, Deressa [22] observed that a complex rainfall pattern was characterized by irregular trends for the past 50 years in southern Ethiopia. Hagdu [24] investigated rainfall during the period 1980–2009 in northern Ethiopia and found high spatial variability in annual and seasonal totals with insignificant trend for all stations. Such contradicting results might be due to the quality and length of data, different types of time series (extremes and averages), different definition of the rainy seasons as well as differences in the trend testing method. The lack of consensus in the literature may also show that there is still considerable uncertainties about the impact of climate change on the hydrological regimes of the region. The main points of concern in this chapter are analyzing of trends in annual and seasonal rainfall in the Upper Blue Nile River Basin (UBNRB) during the most recent historical period by implementing the standard and well-accepted statistical procedures.

2 Materials and Methods

2.1 The Blue Nile River

The water resources of the Nile River are the backbone of Eastern African countries. Ethiopia, the water tower of Africa, contributes about 60–85% of the Nile's annual flow [12, 18, 25]. The river and its tributaries provide water for irrigation and hydropower generation to more than 100 million people in the 11 countries that share the Nile Basin. The Blue Nile River Basin, the main source of the Nile River, connects the Sobat River to the north and drains rugged terrain through deep canyons cut into the Ethiopian plateau (Fig. 2). The Blue Nile originates from Lake Tana in the Ethiopian Highlands, at elevations of 2,000–3,000 m, and contributes about 60–69% of the main Nile discharge as shown in Table 1 [26–29]. The river goes through a steep 900-km decent from its source in Lake Tana at 1,829 m elevation to the Sudan plain at 490 m. The river continues to flow across the flat plain for another 800 km and intercepts two smaller rivers, Dinder and Rahad, bringing the total drainage area to 324,500 km^2 (Fig. 2). At Khartoum, the Blue and White Niles converge to form the Main Nile. About 84% of the annual

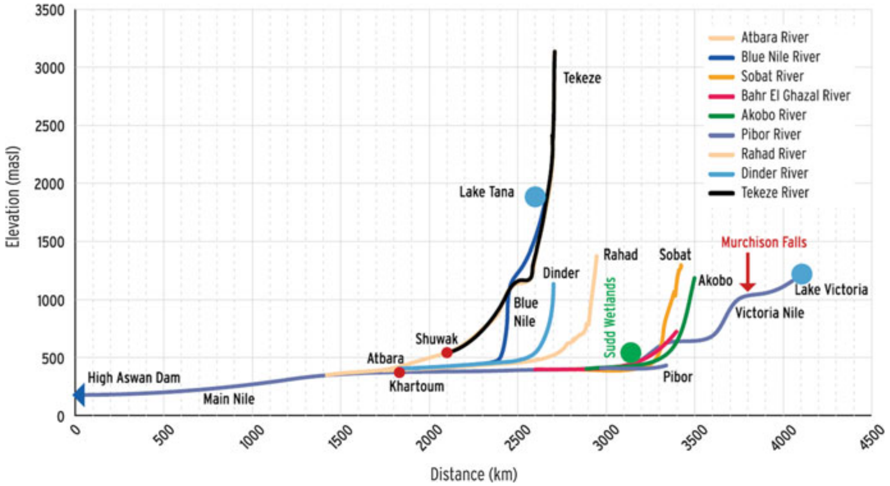

Fig. 2 Longitudinal profiles of major tributaries on the Nile [33]

Table 1 Average annual flows of the Nile River system

Watershed	Annual flow (km^3)	Percentage (%)
Nile at Aswan	84.1	100
Atbara at mouth	11.1	13.2
Blue Nile at Khartoum	48.3	57.4
White Nile at Khartoum	26.0	30.9
Sudd at Malakal	16.1	19.1
Sobat at Malakal	9.9	11.8

runoff in the Blue Nile Basin occurs between June and October, resulting from heavy rains during the single rainy season [29, 30]. The Atbara River, which flows from its headwaters in Ethiopia, has a drainage area of 112,400 km^2 and shares many characteristics with the Blue Nile. The upper portion of its basin has an even greater slope, the rainy season is shorter, and it does not have a large lake at its source. Accordingly, the Atbara River is even more strongly seasonal than the Blue Nile, often receding to little or no flow in the dry season [31].

2.2 *Study Region and Data Set*

The study area is the Upper Blue Nile River Basin (UBNRB). The UBNRB is the part of the watershed of the Blue Nile River Basin, which is under the Ethiopian territory. The UBNRB study areas are located in the western part of Ethiopia, between 7° 45′ and 12° 45′N and 34° 05′ and 39° 45′E and comprises 17% of the area of Ethiopia (176,000 km^2 out of 1,100,000 km^2) [9]. Figure 3 shows the altitude of the UBNRB which ranges from 511 to 4,052 m. In general, the Blue Nile River and its tributaries have a slope toward the northwest. The eastern zone of the basin is characterized by steeper slopes compared to the west and northeast areas [19, 32]. The average annual flow of the Blue Nile River at the Sudan–Ethiopian border represents more than 40% of Ethiopia's total surface water resources, with a volume of about 48,660 million [26, 32]. Consequently, the UBNRB represents a substantial water resource for Ethiopia and for the downstream countries of Sudan and Egypt as well. Forty-nine years (January 1960–December 2008) of daily precipitation data from 22 ground-based meteorological stations in the Upper Blue Nile Basin were used in this study to analyze drought events. The selected stations represent a good spatial coverage across the study region (see Fig. 3).

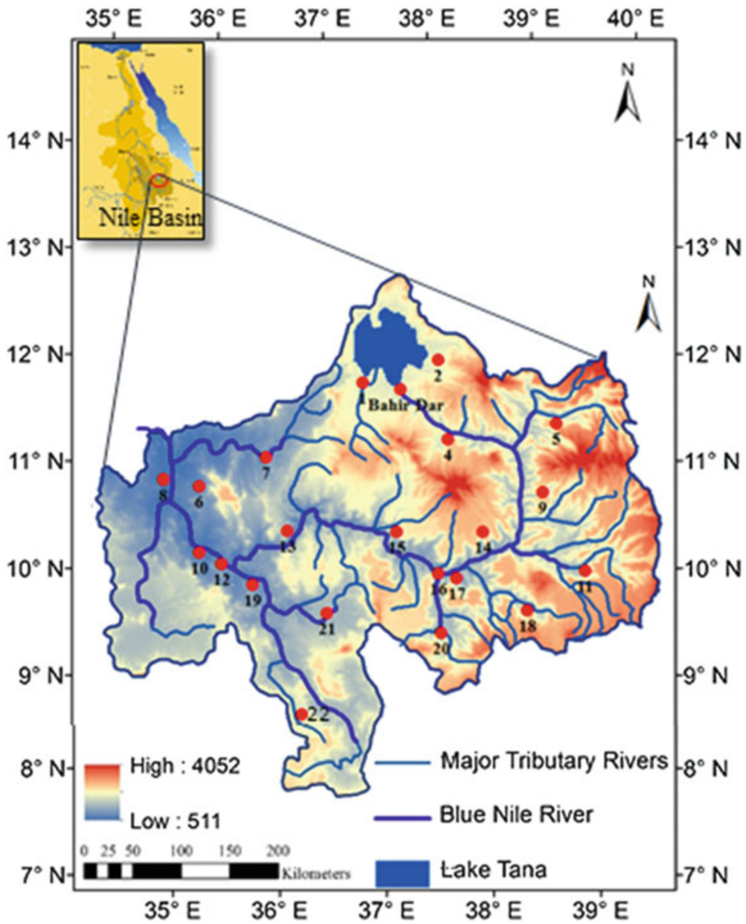

Fig. 3 DEM of the Upper Blue Nile River Basin with locations of meteorological stations

2.3 Trend Analysis

2.3.1 Mann–Kendal Test

The nonparametric Mann–Kendall (MK) test, also known as Kendall's τau test or the Mann–Kendall trend test, is widely used to evaluate trends in hydrological time series [11]. The MK test was applied to examine the trends in the rainfall data series. The MK test is based on the test statistic S defined as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}\left(X_i - X_j\right) \tag{1}$$

where X_j are the sequential data values, n is the length of the data set, and

$$\operatorname{sgn}\left(X_i - X_j\right) = \begin{cases} 1 & \text{if } \left(X_i - X_j\right) > 0 \\ 0 & \text{if } \left(X_i - X_j\right) = 0 \\ -1 & \text{if } \left(X_i - X_j\right) < 0 \end{cases} \tag{2}$$

Mann [34] and Kendall [35] documented that when n $\geq$ 8, the statistic S is approximately normally distributed with the mean and the variance as follows:

$$E(S) = 0 \tag{3}$$

$$V(S) = \frac{n(n-1)(2n+5) - \sum_{p=1}^{u} t_p\left(t_p - 1\right)\left(2t_p + 5\right)}{18} \tag{4}$$

where n = number of data, t_p = the number of ties for the pth value (number of data in the pth group), and u = the number of tied values (number of groups with equal values/ties).

The standardized MK test statistic Z_{MK} is computed by:

$$Z_{\mathrm{MK}} = \begin{cases} \dfrac{S-1}{\sqrt{\operatorname{Var}(s)}} & S > 0 \\ 0 & S = 0 \\ \dfrac{S+1}{\sqrt{\operatorname{Var}(s)}} & S < 0 \end{cases} \tag{5}$$

The standardized MK statistic Z follows the standard normal distribution with mean of zero and variance of one. The hypothesis that there has not trend will be rejected if:

$$\left|Z_{\mathrm{MK}}\right| > Z_{1-\alpha/2} \tag{6}$$

$Z_{1-\alpha/2}$ is the value read from a standard normal distribution table with α being the significance level of the test. At the 99% significance level, the null hypothesis of no trend is rejected if $|Z_{\mathrm{MK}}| > 2.575$; at 95% significance level, the null hypothesis of no trend is rejected if $|Z_{\mathrm{MK}}| > 1.96$; and at 90% significance level, the null hypothesis of no trend is rejected if $|Z_{\mathrm{MK}}| > 1.645$.

2.3.2 The Sen's Estimator of Slope

The method of calculating the Sen's slope estimator requires a time series of equally spaced data [36]. Sen's method proceeds by calculating the slope as a change in measurement per change in time; Sen's estimator of the slope is simply given by the median slope as follows [36, 37]:

$$Q = \text{median}\left(\frac{X_i - X_j}{j - 1}\right) \tag{7}$$

where Q is the slope between data points X_i and X_j, X_i is the data measurement at time i, X_j is the data measurement at time j, and j is the time following time i. A positive value of Q assumes an upward trend and a negative value indicates a downward trend.

3 Results and Discussion

According to the rainfall data analysis, the mean annual rainfall over the Upper Blue Nile River Basin is 1,394 mm which is higher than those of the other subbasin of the Nile basin [9]. The minimum and maximum values of the mean annual rainfall over the UBNRB, within the studied period, are 1,464 and 1,054 with an overall average of 1,260 mm as shown in Fig. 4. The climatic seasons in the UBNRB are classified into three main seasons, namely, long rainy period (Kiremt) from June to September, with the greatest rainfall mainly in July and August; short rain period (Belg) from March to May; and, finally, dry season (Bega) from October to the end of February. The distribution of rainfall is highly variable both spatially and temporally over the yearly seasons [19] (Table 2). Figure 5 shows the mean monthly precipitation, and the corresponding standard deviation, for the Bahir Dar station on the southern shore of Lake Tana. About 80% of the annual precipitation is received during the period of June–September. The standard deviation ranges between 14% of the mean in wet months and 42% of the mean in dry months which indicates inter-annually variability of the monthly precipitation.

3.1 Annual Rainfall Analysis

The first step in trend analysis of annual rainfall is to investigate serial correlation coefficients of the annual precipitation time series to remove its effect in the trend tests. Figure 6 shows the average precipitation trend for the period 1960–2008 for all recording stations. There is much variability, including a general increase in precipitation from 1992 to 1998. The trend in the 1970s and 1980s is a decrease in

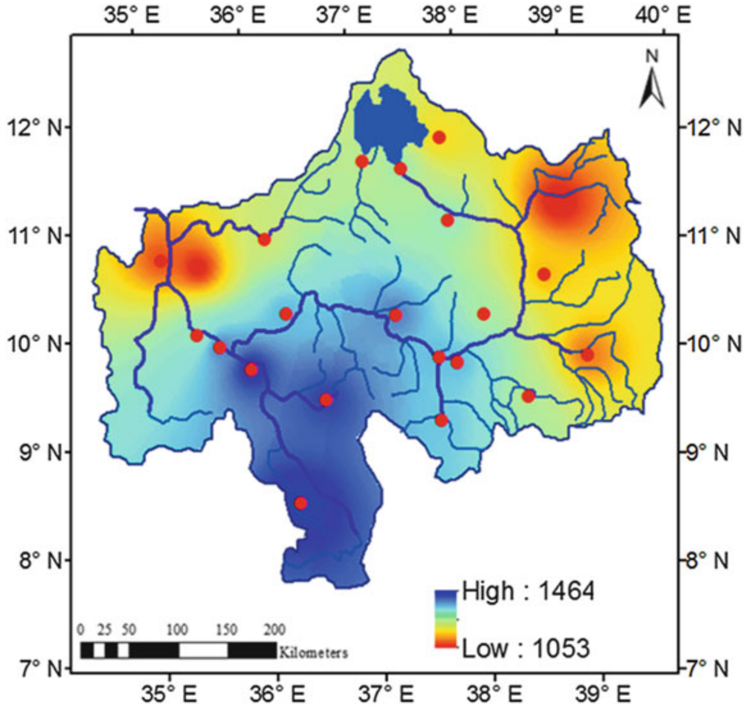

Fig. 4 Mean annual precipitation (mm) over the Upper Blue Nile River Basin (1960–2008)

precipitation. Within the precipitation trend, the mid 1980s (mainly 1984), early 1990s, and 2000s were the lowest on record. Regardless of the variability, the general result obtained from annual average precipitation values indicates a relative no change in trend in time (Fig. 6).

Regarding the Mann–Kendall test, all the rainfall time series were analyzed. For the annual, the rainy season (June–September), and the dry season (October–May), the test was performed independently. The test results of the statistical analysis at 95% confidence level ($p = 0.05$) for the annual rainfall trend detection are presented in Table 3. Thirteen (59%) of the seven stations showed a negative trend. Even though there is a decreasing trend in all of these 13 stations, the trends showed statistical significance, at the 5% significance level, only at one station (station 10) with a range varying from −2.22 to −2.90 mm/year (refer to Table 3 and Fig. 7). On the other hand, the other nine stations showed an increasing trend in rainfall and revealed statistically insignificant trend. The results of annual rainfall are consistent with other annual analysis of rainfall conducted in some other parts of Ethiopia as mentioned earlier [18, 21, 32]. Results presented in Fig. 7 are in agreement with major drought and famine in Ethiopia during the late 1970s and the early 1980s. A decadal analysis by McSweeney [7] reveals that annual precipitation decreased during the 1980s in many parts of Ethiopia and recovered during the

Table 2 Overview of the selected meteorological stations and their annual rainfall properties

Rainfall station	Location		Annual rainfall (mm)					
	Lat.	Long.	Mean	Min	Max	Std.	Skewness	Kurtosis
1	11.69	37.08	1,264	919	1,882	186.8	1.3	5.2
2	11.91	37.81	1,182	864	1,844	191.5	1.5	5.7
3 (Bahir Dar)	11.63	37.43	1,281	905	1,963	201.5	1.4	5.5
4	11.15	37.84	1,292	1,025	1,920	175.2	1.3	5.8
5	11.31	38.88	1,054	665	1,738	194.7	0.9	4.9
6	10.71	35.46	1,062	826	1,302	115.2	−0.2	2.2
7	10.97	36.10	1,245	953	1,641	150.4	0.6	3.1
8	10.77	35.12	1,097	851	1,323	118.7	−0.2	2.2
9	10.65	38.70	1,164	799	1,668	173.9	0.3	3.1
10	10.07	35.42	1,292	1,016	1,540	126.4	−0.3	2.4
11	9.90	39.04	1,123	795	1,384	143.4	0.0	2.2
12	9.96	35.62	1,389	1,094	1,643	131.6	−0.3	2.6
13	10.28	36.26	1,358	1,088	1,617	126.1	−0.3	2.3
14	10.27	38.10	1,276	1,043	1,556	131.9	0.2	2.4
15	10.27	37.29	1,387	1,142	1,676	133.8	0.1	2.6
16	9.88	37.66	1,357	1,058	1,701	135.0	0.3	3.2
17	9.83	37.83	1,357	1,063	1,695	134.4	0.3	3.2
18	9.52	38.47	1,269	985	1,583	130.4	0.3	3.0
19	9.76	35.90	1,448	1,138	1,726	137.6	−0.3	2.7
20	9.30	37.64	1,350	1,014	1,720	135.9	0.4	3.7
21	9.49	36.58	1,430	1,128	1,739	131.2	0.0	3.0
22	8.53	36.29	1,464	1,179	1,784	146.9	0.1	2.5

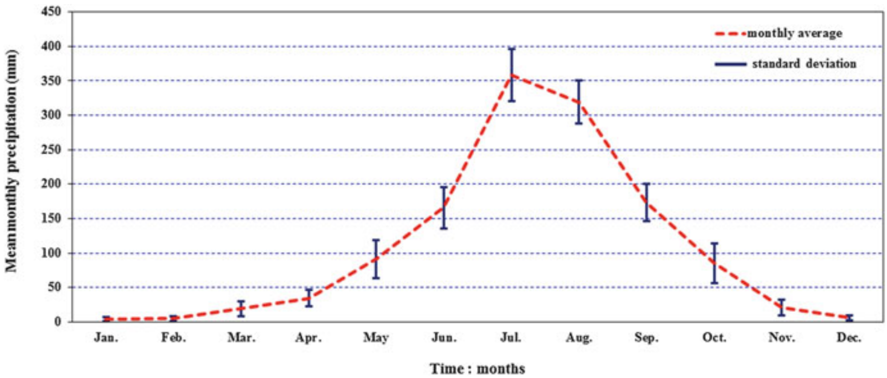

Fig. 5 The monthly average precipitation along with the corresponding standard deviation for Bahir Dar station

1990s and 2000s, with the exception of 2002–2003 when the country experienced the worst drought period.

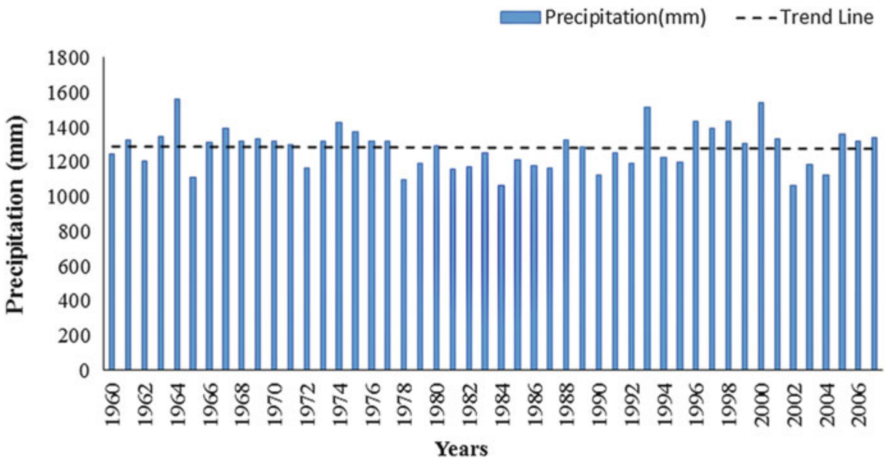

Fig. 6 Average annual rainfall at the Upper Blue Nile River rainfall stations

Table 3 Annual rainfall trend detection for the stations in the Upper Blue Nile River Basin for the study period

Station	Sen's slope (mm/year)	Z_{MK}	Type of trend
1	0.61	0.35	Insignificant
2	1.05	0.67	Insignificant
3 (Bahir Dar)	0.63	0.63	Insignificant
4	0.40	0.28	Insignificant
5	2.26	0.99	Insignificant
6	−2.27	−1.75	Insignificant
7	−0.64	−0.45	Insignificant
8	−2.50	−1.88	Insignificant
9	1.89	1.04	Insignificant
10	−2.90	−1.98	Significant
11	1.85	1.05	Insignificant
12	−2.23	−1.58	Insignificant
13	−1.77	−1.43	Insignificant
14	0.65	0.51	Insignificant
15	−1.44	−1.01	Insignificant
16	−0.11	−0.10	Insignificant
17	−0.21	−0.19	Insignificant
18	0.76	0.47	Insignificant
19	−1.81	−1.20	Insignificant
20	−0.58	−0.33	Insignificant
21	−1.21	−0.97	Insignificant
22	−1.57	−0.99	Insignificant

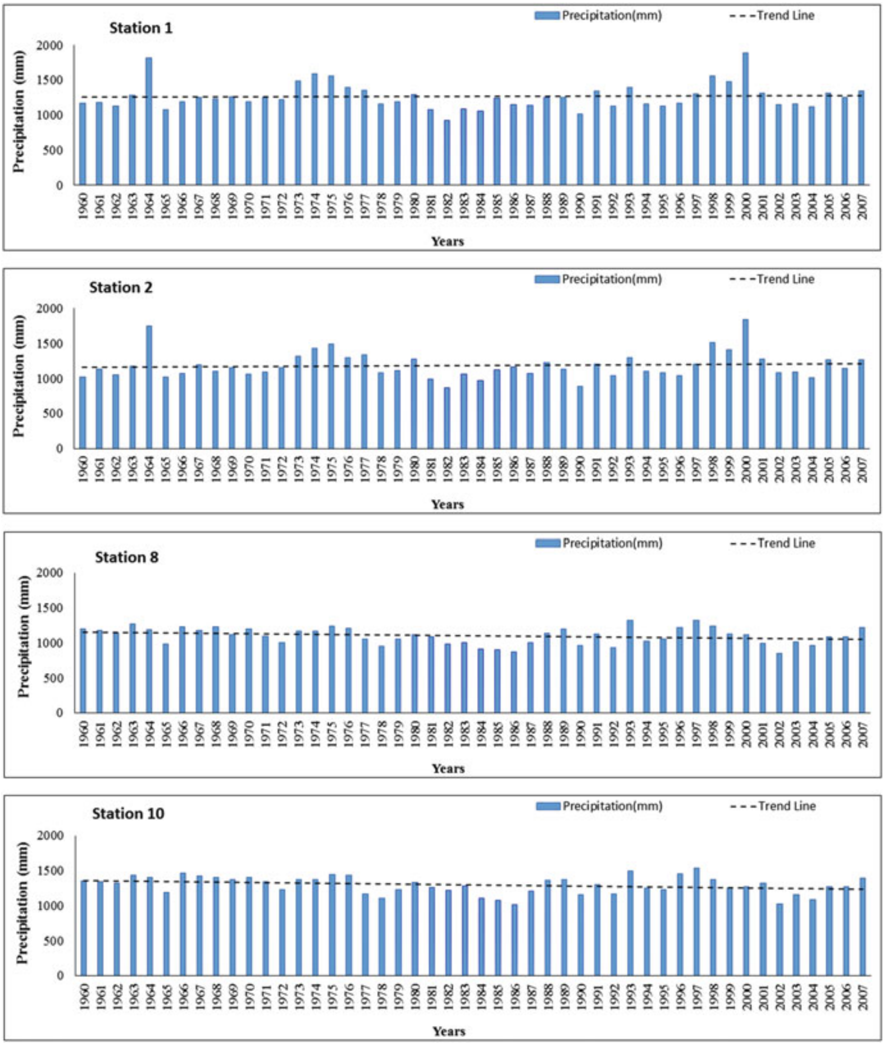

Fig. 7 Variation of annual rainfall for stations 1, 2, 8, and 10 in the Upper Blue Nile River Basin for the period 1960–2008

3.2 Seasonal Rainfall Analysis

According to the analysis performed, the test results for the Kiremt (rainy season) rainfall trend detection are given in Table 4 and Fig. 8 for the study period. During the Kiremt season (June–September), total rainfall showed similar trends to the annual trend pattern presented in Table 3. Ten stations (6, 7, 8, 10, 12, 13, 15, 19, 21, 22) showed negative trends, and spatially, the negative trends dominate in the western part of the river basin with a range varies from −0.40 to −1.9 mm/year.

Table 4 Rainy seasonal rainfall trend detection for the stations in the Upper Blue Nile River Basin for the study period

Station	Sen's slope (mm/year)	Z_{MK}	Type of trend
1	0.46	0.19	Insignificant
2	0.45	0.35	Insignificant
3 (Bahir Dar)	0.65	0.44	Insignificant
4	0.42	0.36	Insignificant
5	1.05	0.39	Insignificant
6	−1.58	−1.70	Insignificant
7	−0.99	−0.83	Insignificant
8	−1.58	−1.70	Insignificant
9	1.38	0.79	Insignificant
10	−1.91	−2.03	Significant
11	0.92	0.76	Insignificant
12	−1.25	−1.48	Insignificant
13	−1.28	−1.29	Insignificant
14	0.98	0.87	Insignificant
15	−0.41	−0.52	Insignificant
16	0.51	0.60	Insignificant
17	0.43	0.49	Insignificant
18	1.09	1.00	Insignificant
19	−1.09	−1.16	Insignificant
20	0.47	0.45	Insignificant
21	−0.64	−0.49	Insignificant
22	−0.41	−0.31	Insignificant

Furthermore, the negative trends were statistically significant at 95% confidence level only at one station (station 10). All positive trends were statistically insignificant trends at 95% level of significance. Comparison of the seasonal and annual rainfall trend analysis results showed that the trends in annual data followed those of seasonal data in the entire basin. The findings presented in this chapter agree with and are similar to other studies previously applied in other parts of Ethiopia [11–13, 21].

4 Conclusion

In this chapter, a statistical analysis of annual and seasonal rainfall was performed at 22 ground-based meteorological stations in the Upper Blue Nile River Basin during 49 years. Trend analyses were conducted by using the nonparametric Mann–Kendall test and the Sen's slope approach. The results highlighted a mix of insignificant positive (increasing) and negative (decreasing) trends in seasonal and annual rainfall at the stations considered. In correspondence with the

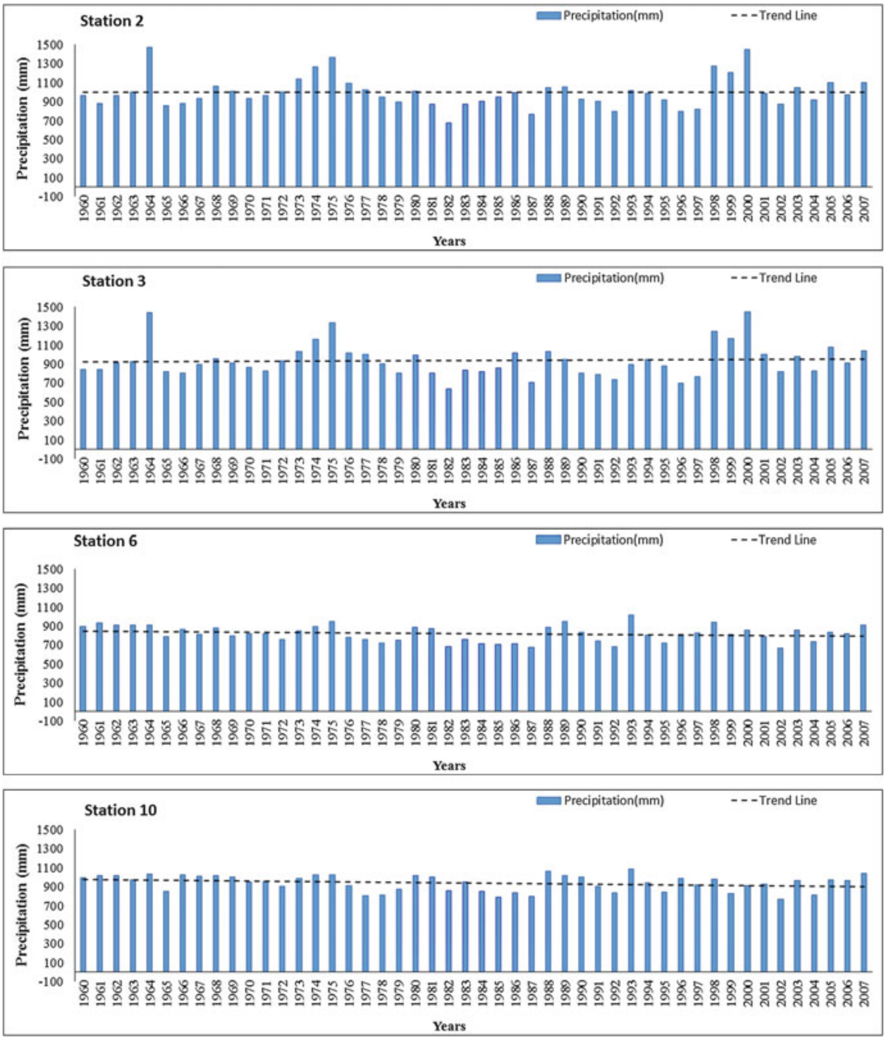

Fig. 8 Variation of rainy seasonal rainfall for stations 2, 3, 6, and 10 in the Upper Blue Nile River Basin for the period 1960–2008

Mann–Kendall test values, Sen's slope also indicated increasing and decreasing the magnitude of the slope. Accordingly, there were 12 stations with increasing trend value along with the increasing slope magnitude in the eastern part and 10 stations with decreasing or negative value in the annual and rainy season rainfall trend analysis in the western part of the basin. Generally, out of the 22 stations surveyed in this chapter, significant trends in annual series are evident only at one station at the rate of -2.9 mm/year, and the significant decreasing trend in rainy seasonal series at the same station was at the rate of -1.9 mm/year. The findings presented in this chapter agree with and are similar to other studies previously applied in other parts of Ethiopia and Eastern Africa region.

References

1. Abtew W, Melesse AM (2014) The Nile River basin. Springer, Cham, pp. 7–21
2. Mares MA (1999) Encyclopedia of deserts. University of Oklahoma Press, Norman
3. Camberlin P (2009) Nile basin climates. The Nile. Springer, Cham, pp. 307–333
4. Evans T (1994) History of Nile flows. In: The Nile: sharing a scarce resource – an historical and technical view of water management and of economic and legal issues. Cambridge University Press, Cambridge, pp. 27–63
5. Kayombo S, Jorgensen S (2006) Lake Victoria. Experience and lessons learned brief. International Lake Environment Committee, Lake Basin Management Initiative. http://www.ilec.or.jp/lbmi2/reports/27_Lake_Victoria_27February2006.pdf
6. Tidwell AC (2006) Assessing the impacts of climate change on river basin management: a new method with application to the nile river. Doctoral dissertation, Georgia Institute of Technology
7. McSweeney C, Lizcano G, New M, Lu X (2010) The UNDP climate change country profiles: improving the accessibility of observed and projected climate information for studies of climate change in developing countries. Bull Am Meteorol Soc 91:157–166
8. Tekleab S, Mohamed Y, Uhlenbrook S (2013) Hydro-climatic trends in the Abay/upper Blue Nile basin, Ethiopia. Phys Chem Earth A B C 61:32–42
9. Khadr M (2016) Temporal and spatial analysis of meteorological drought characteristics in the upper Blue Nile river region. Hydrol Res nh2016194
10. Khadr M (2011) Water resources management in the context of drought (an application to the Ruhr river basin in Germany). Shaker
11. Kiros G, Shetty A, Nandagiri L (2016) Analysis of variability and trends in rainfall over northernEthiopia. Arab J Geosci 9:1–12
12. Addisu S, Selassie YG, Fissha G, Gedif B (2015) Time series trend analysis of temperature and rainfall in lake Tana sub-basin, Ethiopia. Environ Syst Res 4:1
13. Conway D, Persechino A, Ardoin-Bardin S, Hamandawana H, Dieulin C, Mahé G (2009) Rainfall and water resources variability in sub-Saharan Africa during the twentieth century. J Hydrometeorol 10:41–59
14. Mohamed Y, Van den Hurk B, Savenije H, Bastiaanssen W (2005) Hydroclimatology of the Nile: results from a regional climate model. Hydrol Earth Syst Sci Discuss 2:319–364
15. Conway D, Hulme M (1993) Recent fluctuations in precipitation and runoff over the Nile sub-basins and their impact on main Nile discharge. Clim Chang 25:127–151
16. Tesemma ZK, Mohamed YA, Steenhuis TS (2010) Trends in rainfall and runoff in the Blue Nile Basin: 1964–2003. Hydrol Process 24:3747–3758
17. Gebremicael T, Mohamed Y, Betrie G, van der Zaag P, Teferi E (2013) Trend analysis of runoff and sediment fluxes in the upper Blue Nile basin: a combined analysis of statistical tests, physically-based models and landuse maps. J Hydrol 482:57–68
18. Berhanu B, Seleshi Y, Amare M, Melesse AM (2016) Upstream–downstream linkages of hydrological processes in the Nile River basin. In: Landscape dynamics, soils and hydrological processes in varied climates. Springer, Cham, pp 207–223
19. Koch M, Cherie N (2013) SWAT modeling of the impact of future climate change on the hydrology and the water resources in the upper Blue Nile River basin, Ethiopia. In: Proceedings of the 6th international conference on water resources and environment research, ICWRER2013, pp 3–7

20. Onyutha C, Tabari H, Taye MT, Nyandwaro GN, Willems P (2015) Analyses of rainfall trends in the Nile River basin. J Hydro Environ Res 13:36–51
21. Cheung WH, Senay GB, Singh A (2008) Trends and spatial distribution of annual and seasonal rainfall in Ethiopia. Int J Climatol 28:1723–1734
22. Deressa T, Hassan R, Ringler C (2011) Perception of and adaptation to climate change by farmers in the Nile basin of Ethiopia. J Agric Sci 149:23
23. Hany Mostafa HS, El Sheikh M, Kheireldin K (2015) Assessing statistical downscaling to quantify the impact of climate changes of rainfall over the Blue Nile basin. Life Sci J 12:86–95
24. Hadgu G, Tesfaye K, Mamo G, Kassa B (2013) Trend and variability of rainfall in Tigray, northern Ethiopia: analysis of meteorological data and farmers' perception. Acad J Agric Res 1:88–100
25. Nawaz R, Bellerby T (2007) Blue Nile flow sensitivity to projected climatic change until 2100. IAHS Publ Ser Proc Rep 315:284–294
26. Conway D (2000) The climate and hydrology of the upper Blue Nile River. Geogr J 166:49–62
27. Adem AA, Melesse AM, Tilahun SA, Setegn SG, Ayana EK, Wale A, et al (2014) Climate change projections in the upper Gilgel Abay River catchment, Blue Nile basin Ethiopia. In: Nile River basin. Springer, Cham, pp. 363–388
28. Elshamy ME, Seierstad IA, Sorteberg A (2009) Impacts of climate change on Blue Nile flows using bias-corrected GCM scenarios. Hydrol Earth Syst Sci 13:551–565
29. Tabari H, Taye MT, Willems P (2015) Statistical assessment of precipitation trends in the upper Blue Nile River basin. Stoch Env Res Risk A 29:1751–1761
30. Tegegn FE (2010) Can changes in precipitation explain the increased discharge from the Blue Nile River basin?. Master thesis, Natural Geography and Quaternary Geology, Stockholm University
31. Melesse AM, Abtew W, Setegn SG (2011) Nile River basin. Springer, Cham
32. Khadr M (2016) Forecasting of meteorological drought using hidden Markov model (case study: the upper Blue Nile river basin, Ethiopia). Ain Shams Eng J 7:47–56
33. Dumont HJ (2009) A description of the Nile basin, and a synopsis of its history, ecology, biogeography, hydrology, and natural resources. Springer, Cham
34. Mann HB (1945) Nonparametric tests against trend. Econometrica 13:259
35. Kendall MG (1975) Rank correlation methods. Griffin, London
36. Nenwiinia S, Kabanda T (2013) Trends and variability assessment of rainfall in Vhembe South Africa. J Hum Ecol 42:171–176
37. Xu ZX, Li JY, Liu CM (2007) Long-term trend analysis for major climate variables in the Yellow River basin. Hydrol Process 21:1935–1948

Productivity of Rainfed Agriculture of the Upper Nile River

Nader Noureldeen Mohamed

Abstract The importance of rainfed agriculture varies regionally but produces most of the food for poor communities in developing countries. Rainfed agriculture is the source of the bulk of world food and will continue to do so into the foreseeable future. Irrigation plays a very important role; irrigated agriculture worldwide represents only 20% of the agricultural land but produces 40% of world food. The rainfed agriculture is employed by the majority of the world's 1.1 billion farmers (of which 95% live in developing countries). Their share of global agriculture is very large, amounting to 60% of the world food production. Rainfall over the Basin is characterized by highly uneven seasonal and spatial distribution. Most of the Basin experiences only one rainy season – typically in the summer months. Only the equatorial zone has two distinct rainy periods. The reliability and volume of precipitation generally decline moving northward, with the arid regions in Egypt and the northern region of Sudan receiving insignificant annual rainfall. The high temporal variability of rainfall in the Basin is demonstrated by the monthly rain records. Broadly speaking, there are three patterns of seasonal rainfall variation: (1) a single rain peak in June–October, with little or no rainfall in other months, which is experienced in sub-basins of Eastern Nile (Eretria, Ethiopia) and the main Nile (Sudan); (2) a fairly evenly distributed rainfall, with a single peak from April to October, found in northern Uganda and South Sudan; and (3) a twin-peaked distribution, peaking in March–May and September–November, with considerable but lower rain in other months. More than 87% cultivated land in the Nile Basin is using rainfed agriculture, on which the livelihood of the large rural populations of the upper riparian depends. The most important rainfed production systems are as follows: mixed smallholder subsistence rainfed, mixed highland smallholder subsistence rainfed, forest based, mechanized rainfed, nomadic and

N.N. Mohamed (✉)
Department of Soil and Water Sciences, Faculty of Agriculture, Cairo University, Giza, Egypt
e-mail: nadernour@hotmail.com

A.M. Negm (ed.), *The Nile River*, 467
Hdb Env Chem (2017) 56: 467–502, DOI 10.1007/698_2016_108,

seminomadic, lowland smallholder subsistence rainfed, and finally shifting rainfed cultivation or agropastoral.

Keywords Agropastoral, Mechanized rainfed, Mixed rainfed, Nile Basin, Rainfed agriculture, Shifting rainfed, Smallholder

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1 Introduction

Water scarcity already affects every continent. Around 1.2 billion people, almost one-fifth of the world's population, live in areas of scarcity. Another 1.6 billion people, almost one-quarter of the global population, face economic water shortage (meaning that countries lack the necessary infrastructure to take water from rivers and aquifers). It is estimated that by 2030, almost 50% of people on the planet will be living in areas of high water stress with a likely impact on energy and food

Table 1 Distribution of international renewable freshwater [1, 4]

Continent/region	Volume per year (Km^3 per 10^9 m^3)	Percentage of world freshwater resources	Per capita (m^3/year) (2008)
World	43,802	100.0	6,498
Africa	3,931	9.0	4,008
Asia	12,393	28.3	3,037
South America	12,380	28.3	32,165
Central America and the Caribbean	781	1.8	9,645
North America	6,877	15.7	15,166
Oceania	892	2.0	32,366
Europe	6,548	14.9	8,941

security [1]. The semiarid tropic (SAT) is the home to 38% of the developing countries' poor, 75% of whom live in rural areas. Over 45% of the world's hungry and more than 70% of its malnourished children live in the SAT [2, 3]. Even though water is a renewable resource, and there is sufficient water globally to satisfy an expanding and wealthier population, demand for water exceeds supply in many regions of the world. This supply–demand imbalance is most commonly seen in India, China, and the Middle East and North Africa (MENA) region [2]. Table 1 shows the distribution of the freshwater between the world continents.

The importance of rainfed agriculture varies regionally but produces most food for poor communities in developing countries. Rainfed agriculture is the source of the bulk of the world food and will continue to do so into the foreseeable future. Irrigation plays a very important role as irrigated agriculture worldwide represents only 20% of the agricultural land but produces 40% of the world food. Rainfed agriculture employs the majority of the world's 1.1 billion farmers (of which 95% live in developing countries). Their share of global agriculture is very large, amounting to 60% of world food production.

In sub-Saharan Africa, which includes all of the Nile Basin except Egypt, more than 95% of the farmed land is rainfed [3, 5–7]. Most countries in the world depend primarily on rainfed agriculture for their grain food. Despite large strides being made in improving productivity and environmental conditions in many developing countries, a great number of poor families in Africa and Asia still face poverty, hunger, food insecurity, and malnutrition where rainfed agriculture is the main agricultural activity.

The component of water from precipitation that infiltrates into the soil to replenish the root zone is defined as "green water." From an agricultural perspective, transpiration from the green water stock is considered "productive" evaporation that is converted to biomass. Green water use for global crop production is significantly higher than consumptive blue water use (river and groundwater used in irrigation) [7]. Rainfed agriculture, in particular, is highly vulnerable to reduced rainfall and shifts in rainfall timing and distribution. Almost one-third (820 million) of the developing world's rural population live in less favored rainfed regions, characterized by frequent moisture stress (arid and semiarid regions). Current crop yields remain low in many semiarid areas practicing rainfed agriculture, and there is a huge gap between achievable yields on demonstration farm plots and average yields. Yields in Africa have lagged behind. Such low yields experienced on-farm indicate the constraints facing smallholder farmers, both in terms of water scarcity and other inputs, such as soil fertility management, tillage, timing of operations, etc. However, because the yields at present are so low, there is also a lot of room for improvement. The low yields can partly be explained by *water* constraints, by lack of sufficient *nutrients* (poor soils, under-application of manure and/or inorganic fertilizers), and by inadequate soil management.

Under rainfed conditions, crop growth is subject to the random variability of rainfall in space and time. In tropical regions, rainfall variability is particularly high, as a result of the erratic, high-intensity characteristics of the rainfall. Also, as a rule of thumb, the variability of rainfall over time increases with decreasing annual and seasonal rainfall levels. This means that a semiarid location with 500 mm of rainfall may have an annual variability of 30–40%. Thus, in drier areas, the variability of rainfall tends to be higher than in wetter areas. Rainfall variability is strongly related to crop yields in rainfed tropical agriculture, particularly in semiarid and dry subhumid areas (rainfall between 400 and 900 mm/a) where water is a major constraint in food production (see Table 1).

2 Key Factor of the Agriculture and Food Security in the Nile Basin

The following are the main key factors of the agriculture and food security in the Nile Basin [8, 9]:

1. The agricultural sector is of great importance to the Nile Basin countries as it is a major contributor to gross domestic product (GDP), employment, and food security.
2. Agriculture is the largest water-consuming sector.
3. Close to 90% of the land currently used for agriculture is under rainfed farming systems. These systems are characterized by subsistence-level production and low yields of crops and livestock.
4. There is about 5.6 million hectares of land under irrigation or equipped with irrigation facilities in the Nile Basin. A large proportion – 97% – of the land is located in Egypt and Sudan, with the remaining 3% distributed among the upper riparian states. Productivity and water-use efficiency are high in the irrigation schemes in Egypt, and on commercial irrigation schemes in the rest of the Basin, but generally low in the large smallholder irrigation schemes in Sudan.

5. The potential of the agricultural sector is large, but it is held back by constraints in both the natural resource base and the policy, institutional, and economic environment.
6. The agro-processing sector in the region – except for that in Egypt – is poorly developed.
7. Production levels for food crops have been rising over the years, but food production in the Nile Basin countries falls short of local demands, and all countries are net food importers.
8. To produce sufficient food to feed the Basin population and generate surplus for regional trade, the Basin countries need to concurrently implement a wide range of measures targeting the multiple constraints affecting the agricultural sector.
9. The present situation of dominance of smallholder rainfed subsistence farming in the upper riparian countries is likely to persist to 2030 and beyond. To improve rural livelihoods and enhance food security in the region, it will be necessary, therefore, to improve the productivity of this farming system through, for example, introducing water and soil conservation techniques, providing quality seeds, and encouraging the use of fertilizers.
10. From the perspective of water management, interventions to increase agricultural productivity should include programs to increase rainwater harvesting, expand irrigated areas, improve the water-retention properties of soil in the upstream countries, and improve productivity and water-use efficiency in the downstream countries.
11. Also, yields can be increased by improving management of rainwater by water harvesting to control water loss and govern the excessive runoff that causes soil erosion. Management goal should be to maximize both soil infiltration rate and the water-holding capacity to increase the available water in the soil for crop growth. This infiltration will result in improvements in the quality of natural ecosystems and of water in aquatic ecosystems [4, 10].
12. Policy on water resources management for agriculture remains focused on irrigation, while the framework for integrated water resources management at watershed and basin scales concentrates primarily on allocation and management of blue water in rivers, groundwater, and lakes. What is needed is effective integration that focuses on investment options for water management across the continuum from rainfed to irrigated agriculture and which incorporates a multi-sectoral approach.
13. There is generally enough rainfall to double and often even quadruple yields in rainfed farming systems, even in water-constrained regions. But it is available at the wrong time, causing dry spells, and much of it is lost. Apart from water, upgrading rainfed agriculture requires investments in soil, crop, and farm management and improved infrastructure and markets and better and more equitable access to and security over land and water resources. To improve production, and thus rural livelihoods in rainfed areas, rainfall-related risks need to be reduced, which means that investments in water management are entry point to unlock the potential in rainfed agriculture.

Added to the above, population and food security are the two main factors leading to the extension and the need for more developed agriculture in both rainfed and irrigated agriculture.

3 Population Size in the Nile Basin Countries

The combined population of the Nile riparian countries is 437 million in the year 2012 [8], which are about 41% of the population of Africa. Ethiopia has the highest population (94 million) closely followed by Egypt (91 million) and DR Congo (69.6 million), while Burundi (8.7 million) and Eritrea (5.6 million) have the smallest.

The combined population living within the Basin area in the 11 riparian countries is 238 million (or 54% of the total population of the Nile Basin countries).The proportion of the population of each country that lives within the Basin ranges from 99% for Uganda down to 4% for DR Congo. In terms of actual numbers of people, Egypt has the largest population residing within the Basin area (80.4 million) followed by Uganda (35.4 million) and Ethiopia (34.6 million), while DR Congo has the smallest population in the Basin area (2.6 million).

The Nile Basin has three of the heaviest population concentrations in Africa: surrounding Lake Victoria in Kenya and Uganda (see Fig. 1) (more than Tanzania in south shore of the lake), in the Ethiopian Highlands in the Blue Nile banks and its tributaries, and along the banks of the Nile in Egypt. While Egypt only accounts for 9% of the Basin's area, it holds almost one-third of its population. In contrast, almost 64% of the Nile Basin falls in Sudan, but a little less than 40 million people, or about half as many as in Egypt, live there [11]. The 35 million Ugandans within the Basin live on only 7.6% of the Basin's area. Kenya's 1.6% of the Basin has a higher population density, averaging about 320 people per km^2. Ethiopia has about 35 million people within the Nile Basin, but with 363,315 km^2 in area; population density is lower at about 97 people per km^2. In total, almost 224 million people live within the Basin, representing almost of one-quarter of Africa's population. Four of the Basin's 11 countries have population growth rates in the top ten globally; all but two are above the mean growth rate for Africa and all are well above the global average [9]. While growth rates within the Basin are expected to decline, most projections are still well above 2% per year over the next two decades. Urban populations are growing rapidly throughout the Basin. Burundi is the most rural of any of the Basin countries with only 11% of its people in cities, although its urban areas are growing at 6.8%/year [9, 12]. Sudan and Egypt are the most urban of the Nile Basin countries with 45.2% and 42.8% of their respective populations living in cities. By 2030, it is expected that in half of the Basin's countries, the majority of their people will live in cities. The dense population surrounding Lake Victoria has grown faster than Africa's overall population during every decade since 1960. One estimate of the population in 2010 shows over 35 million people living within 100 km of the lake and twice that many people living within Lake Victoria's watershed, which extends across Rwanda, Burundi, Tanzania, Uganda, and

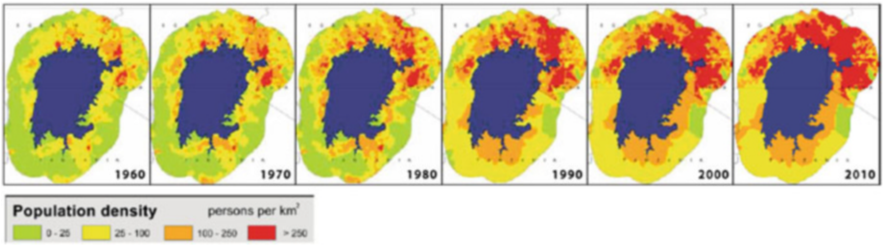

Fig. 1 The dense of rural population surrounding Lake Victoria since 1960 [11]

Kenya [13, 14]. The lake's resources are crucial to the livelihoods of many of these people and significant to all of them. The expanding population has led to increased deforestation, land conversion, agriculture, livestock numbers, industrialization, waste disposal, and fishing pressure [15]. This dense population and the consequent changes in the surrounding environment have had a profound impact on the lake and the ecosystems of which it is a part. With 11 countries and 224 million people sharing the Nile's waters across very different climatic regions, water management, particularly transboundary water management, is very complex. In an area characterized by water scarcity and poverty, rapid population growth will likely compound the difficulty for the foreseeable future.

The Nile Basin has a large population that is growing at a much faster pace than the ability of governments to improve socioeconomic conditions (Fig. 2). Given the economic and natural resource limitations in the Basin, it is clear that, for now, the challenges posed by the rising population outweigh the likely benefits. It is imperative, therefore, that countries increase funding to population programs to try to slow down the pace of population growth. Countries also need to increase funding to programs promoting integrated rural development and dealing with the rapid rate of urbanization. A large proportion of the population in the Nile riparian countries resides in the rural areas and intimately depends on agriculture – and hence on the natural resources base – for their livelihood and food security. Policies and investments aimed at promoting rural development, with a focus on improving rural agriculture productivity coupled with sustainable and efficient natural resources management, are of critical importance for turning the rising population from a burden to an advantage. A doubling of the population in 40 years – in seven out of 11 riparians – may well be beyond the ability of some countries to deal with individually. This signals the importance of strengthening regional integration as a way of promoting general economic development.

A promising area for interbasin cooperation is agricultural trade, which can support regional food security while simultaneously fostering much-needed rural development. Other possible areas for cooperation include trade in energy, interconnection of the power grid, infrastructure development, education and research, and creation of large unified markets for goods and services.

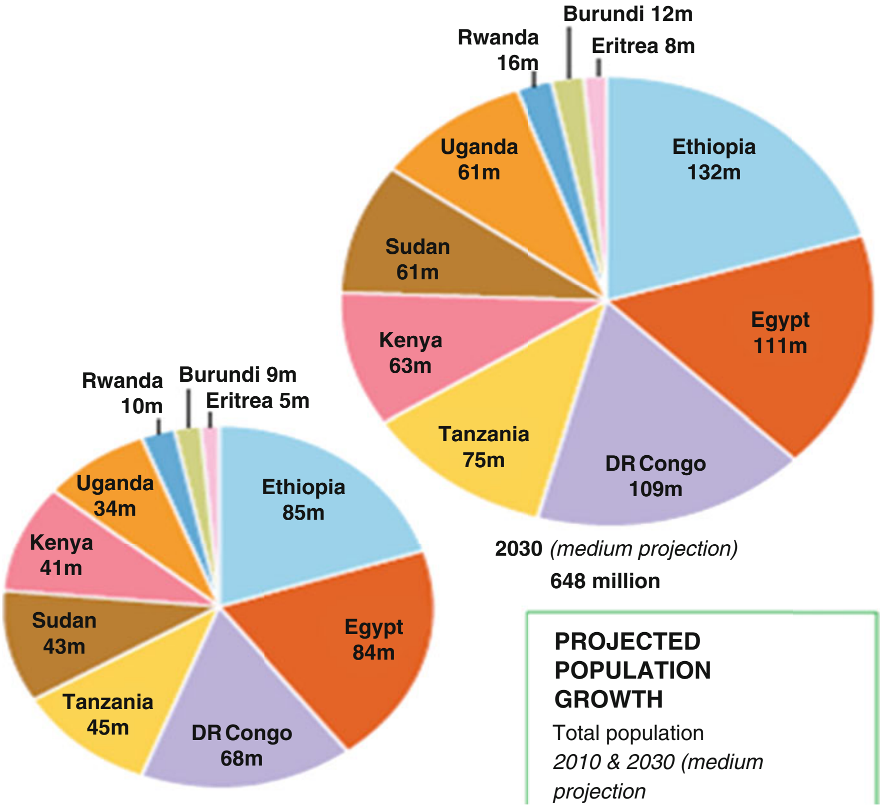

Fig. 2 Projected population growth in the Nile Basin countries in 2030 compared to 2010 where it was 424 million [8]

3.1 *Summary of the Population Distribution of the Nile Basin*

The Nile Basin countries have a combined population of 437 million, 54% of which (238 million) resides in the Nile Basin.

- Water availability appears to be the chief determinant of population distribution in the Basin. In Egypt and Sudan, population is largely concentrated along the course of the Nile River, while in the upstream countries it follows the pattern of rainfall distribution.
- The population in the region is rising rapidly, presenting governments with both opportunities and challenges. The rising population increases the availability of labor for economic production and ensures a large market for food produce, manufactured goods, and services.
- But the rising population also increases degradation of natural resources, puts pressure on economic infrastructure (transport, education, health, water, and

power and telecommunication facilities), increases food security concerns, and leads to rural–urban migration, with the attendant problems of rapid urbanization.

- The factors maintaining high population growth rates are numerous, including widespread poverty, illiteracy, cultural norms, low access to reproductive health services, lack of empowerment, and civil war.
- Concerted efforts by the riparian governments at addressing high population growth rates in the 1980s and 1990s produced sharp reductions in fertility rates. Fertility rates have continued to decline in the region but more slowly.
- About 72% of the Basin population resides in rural areas. The dominance of rural populations is predicted to persist to 2030 and beyond in most Nile Basin countries.
- Considering that the factors that enabled a large population to make a positive contribution to economic development are not well established in most of the Nile Basin countries, the challenges posed by the rising population far outweigh its benefits and threaten to prevent these countries from becoming middle-income countries by 2025 or 2030.
- To achieve the ultimate goal of slowing the rate of population growth, the Basin states need to increase funding for activities aimed at managing the population growth and to intensify efforts at holistic rural development.

4 Water Resources and Water Uses in the Nile Basin

Globally, about 70% of the earth's freshwater is used for agricultural production. However, the globe's water resources are unevenly distributed, and many areas with some of the highest rural and urban populations are located where there is limited water and consequently great water scarcity. Generally, the pattern of vegetation in Africa largely mirrors its climatic zones, with areas of high rainfall producing the greatest volume of biomass, or primary productivity. On a broad scale, [16] has defined the vegetation of Africa in terms of eight major biomes – large areas with similar patterns of vegetation, soils, fauna, and climate. Approximately 66% of Africa is classified as arid or semiarid, with extreme variability in rainfall [17]. There are three main deserts: the Sahara in the north and the Kalahari and the Namib deserts in southern Africa. They are situated around the Tropic of Cancer in North Africa and the Tropic of Capricorn in the south (see Fig. 3). Other arid to semiarid areas include the belt along the eastern coast of Africa and up to the Horn of Africa. More than 40% of Africa's population lives in the arid, semiarid, and dry subhumid areas where demand for water and other ecosystems services is on the rise [18–20]. Droughts during the past three decades and land degradation at the desert margins, particularly the Sahara, have raised concerns about expanding desertification [20]. The full nature of this problem and the degree to which human activities and climate change are contributing to it are still being determined.

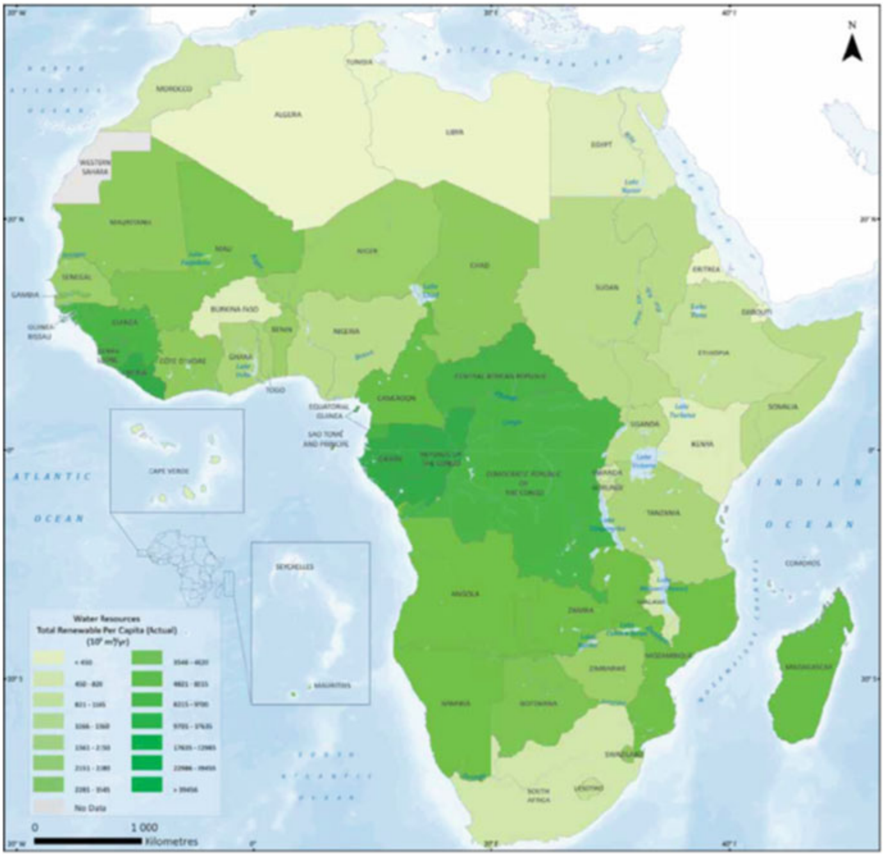

Fig. 3 Renewable water resources in Africa [4]

However, the negative impact that these degraded lands have on the livelihoods of the people who attempt to utilize them is well documented [16].

The Nile Basin is identified as one hot spot where there will be increased water stress in the future. Within the Basin, water resources are also unevenly distributed, and some countries and regions have more water than others. One of the fundamental challenges is that upstream or riparian use of water affects downstream users, and how is it possible to share a basin's water in an equitable manner, when some regions have more water than others. Egypt is already one of the world's most water-scarce countries and is unable to produce enough food for its population. Increased population pressure and upstream agricultural development, mainly in irrigation projects but also different forms of rainwater harvesting, will affect the volume of water in the Nile reaching Sudan and Egypt and hence their food security. Both now and in the future, all countries in the Nile Basin depend and will depend, some more than others, on the utilization of the Nile for their development. Figure 4 shows the rainfall distribution map in Africa.

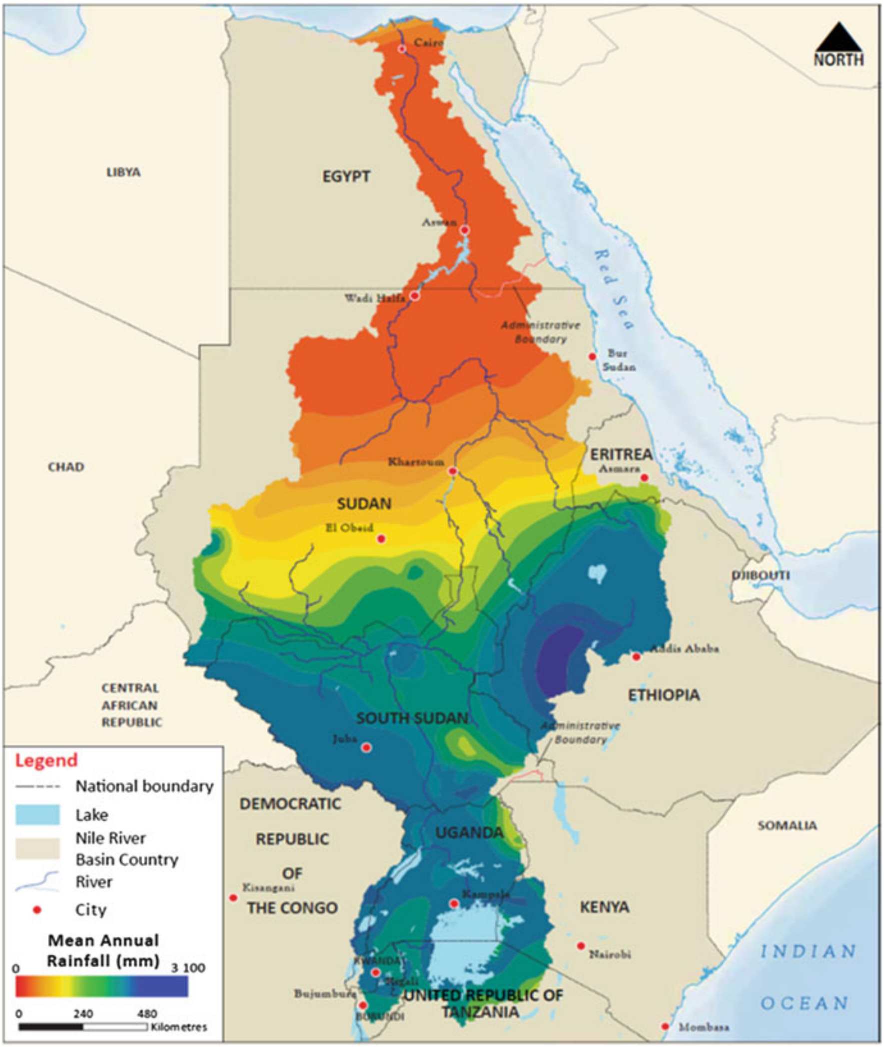

Fig. 4 Rainfall map in the Nile Basin [16]

4.1 *Annual Rainfall Distribution*

Rainfall over the Basin is characterized by highly uneven seasonal and spatial distribution. Most of the Basin experiences only one rainy season – typically in the summer months [8]. Only the equatorial zone has two distinct rainy periods. The reliability and volume of precipitation generally decline moving northward, with the arid regions in Egypt and the northern region of Sudan receiving insignificant annual rainfall. The spatial variability of rainfall is clearly illustrated by the pattern

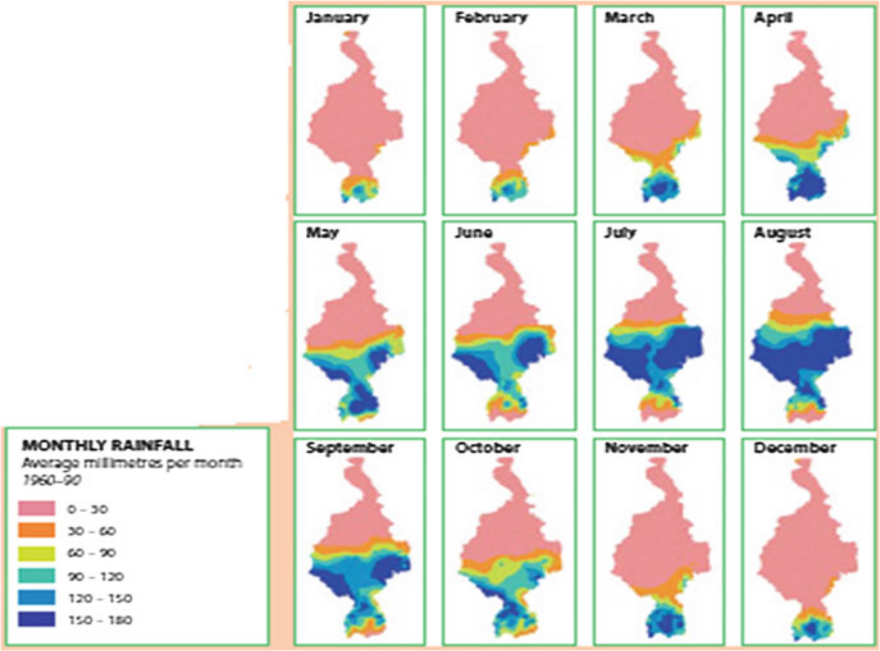

Fig. 5 Rain pattern in the Nile Basin areas [8]

of vegetation and distribution of surface water bodies in the Basin. Large parts of the Nile watershed do not generate runoff. In fact, the main runoff-producing areas are limited to the Ethiopian Highlands and the Equatorial Lakes Plateau, with some contribution from western South Sudan. The relatively small size of the runoff-producing area is central to explaining the very low runoff coefficient of the Nile (3.9%) [8].

Total Nile discharge represents a depth of less than 30 mm if spread over the entire watershed.

4.1.1 Seasonal Rainfall Distribution

The high temporal variability of rainfall in the Basin is demonstrated by the monthly rain records. Broadly speaking, there are three patterns of seasonal rainfall variation (see Fig. 5) [8]:

- A single rain peak June–October, with little or no rainfall in other months. Found in sub-basins of Eastern Nile (Eretria, Ethiopia) and main Nile (Sudan).
- A fairly evenly distributed rainfall, with a single peak from April to October. Found in northern Uganda and South Sudan.
- A twin-peaked distribution, peaking in March–May and September–November, with considerable but lower rain in other months.

5 Rainfed Farming Systems

Over 87% of cultivated land in the Nile Basin is under rainfed agriculture, on which the livelihood of the large rural populations of the upper riparian depends. The most important rainfed production systems are as follows [8, 21].

5.1 Mixed Smallholder Subsistence Rainfed

Mixed smallholder subsistence rainfed agriculture is found in the subhumid and humid parts of the Nile Basin at altitudes between 500 and 1,500 meters above sea level (ASL). Farmers grow cereals and legumes primarily for household consumption and some minor crops for cash. Usually, they also keep a few livestock to provide milk, meat, manure, hides, and draught power. Poultry is raised as a source of cash flow to cover small household essentials. Productivity for most crops is low – less than 2 ton/ha. Livestock productivity is also low. Typically, a family owns less than 1 ha of land, but this varies considerably across the Basin. The land is mostly worked by family members, using locally made hand tools. Inputs such as fertilizers or pesticides are used in a very limited way, if at all. Occasionally, simple small-scale supplementary irrigation is carried out.

5.2 Mixed Highland Smallholder Subsistence Rainfed

Mixed highland smallholder subsistence rainfed agriculture is found in the highlands of Ethiopia and Eritrea, and in the Equatorial Lakes region above 1,500 meters altitude, where rainfall usually exceeds 1,000 mm/year. Deeply entrenched traditional crop and livestock husbandry practices under temperate climatic conditions produce a wide range of fruits, vegetables, cereals, and pulses, although productivity is low. The livestock are mainly of indigenous breeds, with relatively few improved stocks and low productivity. Most of the labor is done by the family, using locally made hand tools. Supplementary irrigation is rare. Poverty is high, as markets for any excess produce are usually distant and unreachable because of poor transport infrastructure. The average human population density is high, and the land has become fragmented, with average farm sizes of less than 0.5 ha. Years of continuous cultivation have depleted the soils of nutrients and led to advanced soil degradation. This is compounded by degradation resulting from overstocking of rangelands.

5.3 Forest Based

Forest-based farming, mainly found in southwestern Ethiopia, depends on the extraction of forest products from dense and intact forest ecosystems that receive rainfall almost all year round. Areas with forest-based farming systems are usually physically isolated and have low population and livestock densities. Shifting cultivation is practiced, with new fields cleared annually.

5.4 Mechanized Rainfed

Mechanized rainfed farming is mainly confined to the eastern and western regions of Sudan and South Sudan, with isolated occurrence in other Upper Nile countries. Production which targets local and export markets is dominated by industrial crops, notably coffee, tea, oil palm, and rubber, as well as cereals and fruits. In Sudan, this farming system produces about 70% of the country's sorghum, 40% of its sesame and nearly its entire sunflower and guar bean crop. This production system consists of consolidated farms larger than 1,000 ha and is predominantly rainfed. Farm operations such as land preparation, planting/seeding, cultivation, harvesting, and transport are largely mechanized.

The productivity of the mechanized rainfed operations falls into two distinct categories. It is low for the extensive cereal farms in Sudan that do not apply agricultural inputs. By contrast, it is generally high for large-scale commercial farms in other parts of the Basin, which have relatively high fertilizer use and apply herbicides for weed control.

5.5 Nomadic and Seminomadic

Nomadic and seminomadic farming describes the transhumance, pastoralist livelihood practiced in areas under arid and semiarid climatic conditions and sparse population. The rainfall in these areas ranges from 100 mm/year to 500 mm/year, while annual temperature ranges are between 26°C and 35°C, although in some areas it can go as high as 45°C. Other characteristics are sparse vegetation and scarce surface water. Areas under this farming system are prone to drought and are therefore unsuitable for crop production. Different species of livestock are kept, and seasonal migration practiced, in order to minimize risk. The livestock, mainly cattle, camels, and sheep, with some goats, are raised entirely on natural rangelands, which are communal resources with no legal land-tenure system. Water resources are mostly communally owned, although in some areas they belong to individuals or families.

Infrastructure development is weak, making transport and communication within these regions difficult. There are few livestock markets established in these remote areas. Livestock diseases are rampant in the Nile Basin and affect all livestock types, rendering productivity and production low. There are frequent conflicts over forage and water among the different clans. Rainfall in the pastoral production regions is erratic and unreliable for fodder production.

5.6 Lowland Smallholder Subsistence Rainfed

Lowland smallholder subsistence rainfed is found in the Savanna belt where annual rainfall ranges from 300 mm to 500 mm/year. It combines traditional extensive rainfed cultivation with livestock keeping and is vulnerable to drought, with frequent crop failures and livestock deaths. It is further characterized by low levels of productivity and technology use.

5.7 Shifting Rainfed Cultivation/Agropastoral

Shifting rainfed cultivation/agropastoral farming combines the keeping of livestock and cultivation of crops for subsistence and sale. Traditional rainfed crop production is carried out, with "slash and burn" methods used to turn bush lands into farmland (shifting cultivation). Camel, indigenous breeds of cattle, sheep, and goats are all raised. The livestock graze on communal land near their permanent cropping areas, on fallow land during winter, and throughout the area after crops have been harvested. This farming system is found predominantly in the cattle corridor of Uganda and parts of Ethiopia, South Sudan, and Sudan. It also occurs in parts of Kenya and Tanzania. Loss of livestock due to stock theft is a common problem, while soil and land degradation is on the increase from overstocking of communal rangelands.

6 Production of Food and Cash Crops Under Rainfed Agriculture

The major food crops grown in the Nile Basin include cereals (barley, maize, millet, rice, sorghum, wheat), pulses (beans, chickpeas, cowpeas, garden peas, pigeon peas), tubers (cassava, potatoes, Irish potatoes, yams), oil seeds (groundnut, sesame, soya bean, sunflower), and fruits and vegetables. Main cash crops include coffee, tea, sugarcane, cotton, and tobacco. Production levels for 2010 are shown in Tables 2 and 3. This indicates that the major producers of food crops in the Basin

Table 2 Production of major cash crops, 2010 (tons) FAOSTAT (2012)

Country	Tea	Coffee	Sugarcane	Cotton	Tobacco
Burundi	8,025	6,821	131,730	731	1,400
DR Congo	2,791	31,840	1,827,140	–	4,000
Egypt	–	–	15,708,900	137,000	–
Eretria	–	–	–	–	–
Ethiopia	5,300	270,000	2.400.000	22,400	5,700
Kenya	399,000	42,000	5,709,590	958	14,156
Rwanda	24.500	25,980	63,000	–	7,500
Sudan	–	–	7,526,700	59,300	–
Tanzania	36,000	40,020	2,750,000	110,000	65,000
Uganda	40,000	162,000	2,400,000	25,500	25,700

are Egypt, Ethiopia, Rwanda, Tanzania, and Uganda, while the major producers of cash crops are Egypt, Kenya, Sudan, and Tanzania. The inadequacy in local food production is strikingly illustrated by the import–export balance for cereals. The cereal trade balance is a convenient (proxy) indicator for food surplus because cereals constitute a vital component of the diet in the Nile Basin countries and because they are predominantly traded across international boundaries in primary form. Analysis of the trade balance for the region over the past 20 years reveals that cereal imports are consistently greater than exports and that the gap between imports and exports is large and increasing. In each Nile riparian country, the domestic cereal production (and by inference food production) falls short of national demand.

Yields for most crops in the upstream countries are low, typically one-sixth to one-half of the yields in Egypt. Although production levels for food and cash crops have been rising over the years, the rate of increase has not kept pace with the rate of population growth.

7 Organic Farming

Organic produce is an emerging niche market that farmers in the Nile Basin could take advantage of to increase earnings from their farm produce. Organic farming is a form of agriculture that relies on techniques such as crop rotation, green manure, compost, and biological pest control. Organic farming uses fertilizers and pesticides but excludes or strictly limits the use of synthetic fertilizers, pesticides (which include herbicides, insecticides, and fungicides), plant growth regulators such as hormones, livestock antibiotics, food additives, genetically modified organisms, human sewage sludge, and nanomaterials. Many farmers in the Nile Basin operate “low input” production systems due to the high cost/unavailability of agrochemicals and so can relatively easily make the technical transition to organic production.

Table 3 Production of major food crops, 2010 (tons) FAOSTAT (2012)

Country	Bananas	Cassava	Dry beans	Maize	Potatoes	Rice (paddy)	Sorghum	Sweet potatoes	Vegetables (fresh)	Wheat
Burundi	136,564	187,901	201,551	126,412	9,320	83,019	83,023	303,432	403,000	9,034
DR Congo	316,472	15,049,500	115,247	1,156,410	94,826	317,231	6,140	247,011	370,000	8,841
Egypt	1,028,950	–	52,904	7,041,100	3,643,220	4,329,500	701,629	370,905	574,952	7,177,400
Eritrea	–	–	300	20,500	140	–	66,700	–	43,300	27,300
Ethiopia	171,700	–	263,100	4,400,000	785,800	25,200	2,997,400	401,600	682,800	3,000,000
Kenya	791,570	323,389	390,558	3,222,000	450,000	80,042	164,066	383,590	596,100	511,944
Rwanda	30	2,377,210	327,497	432,404	1,789,400	67,253	161,229	840,072	51,900	77,193
Sudan	85,300	13,500	16,000	35,000	315,000	23,350	2,630,000	225,000	641,900	403,000
Tanzania	2,924,700	4,392,170	950,000	4,475,420	750,000	1,104,890	788,800	1,400,000	1,500,000	62,130
Uganda	600,000	5,282,00	460,000	1,373,000	695,000	218,111	500,000	2,838,000	760,000	21,500

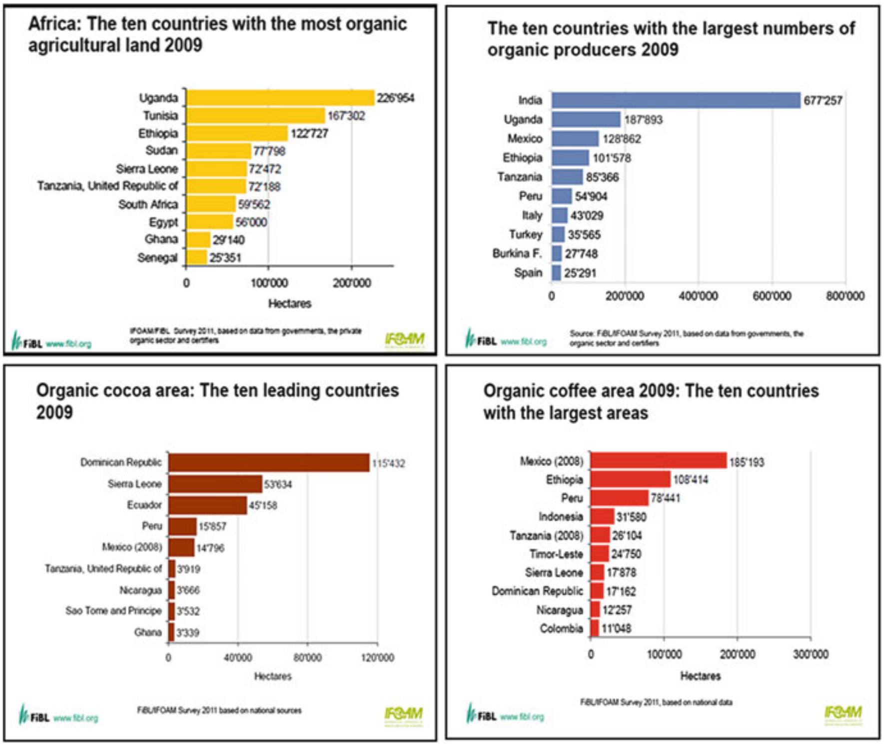

Fig. 6 Organic producers in Africa and the world [20]

A diversity of organic crops are produced by the farmers in the Basin, including bananas, coffee, cocoa, tea, fruits, cotton, sesame, cereals, oils, nuts, honey, vegetables, and sugar. The level of production per country is difficult to ascertain due to limited availability and/or absence of systematic organic agriculture data collection system(s) in the Nile Basin countries. The scanty available information indicates that in 2007 Uganda had an estimated 250,000 ha with 60,000 farmers under certified organic production, Kenya had 181,500 ha with 35,000 farmers, Tanzania had 85,000 ha with 55,000 farmers, and Ethiopia had 150,000 ha with 148,812 farmers [18, 19]. The challenges faced by organic farmers include vigorous weeds, low soil fertility, uncertain water availability, high costs of international inspection and certification, consistently rising volumes to meet market orders, and limited extension services for organic agriculture [18, 19] (see Fig. 6).

Table 4 Food security in the Nile Basin countries

Country	Dietary energy supply	Undernourishment	Cereal trade balance	Intra-basin trade in agricultural and processed food products		Fertilizers	Cereal yield
	Kcal per person per day 2005–2007	As % of total population	Export–import 1,000 tons 2005–2009	Imports 2009 million US$	Exports 2009 million US$	Kg used per hectare of arable land 2005	Tons per hectare 2009
Burundi	1,680	62%	−63.7	16.2	16.1	3.4	1.3
DR Congo	1,590	69%	−722.3	–	–	–	0.8
Egypt	3,160	Less than 5%	−9,003.7	263.5	246.6	732	7.6
Eritrea	1,590	64%	−235.1	–	–	2.3	0.9
Ethiopia	1,950	41%	−1,166.8	14.1	84.7	12	1.6
Kenya	2,060	31%	−1,374.8	117.8	476.8	38	1.2
Rwanda	2,050	34%	−91.5	98.1	41.2	2.6	1.1
S Sudan	1,890	47%	–	–	–	–	–
Sudan	2,270	22%	−1,863.6	–	–	10	0.6
Tanzania	2,020	34%	−654.4	39.1	103.8	1.1	1.2
Uganda	2,250	21%	−425.7	104.4	364.2	2.6	1.5
Source	FAOSTAT (2011)	FAOSTAT (2011)	FAOSTAT (2011)	FAOSTAT (2001)		WB, African Development Indicators	

8 Food Security in the Nile Basin

Food security is defined as the point at which “all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life” [22] and as “a necessary if not sufficient basis for poverty alleviation” [23]. According to the World Food Council, food security implies two things. First, food is available, accessible, and affordable – when and where needed – in sufficient quantity and quality. Second, it implies an assurance that this state of affairs can reasonably be expected to continue and that it can be sustained. To put it simply, food security exists when adequate food is available to all people on a regular basis. The World Food Council [24] states that chronic food insecurity is a continuously inadequate diet caused by the inability to acquire food. It affects households that persistently lack the ability either to buy food or produce their own. Transitory food insecurity is a temporary decline in a household’s access to enough food. It results from instability in food prices, food production, or household incomes – and in its worst form produces famine [25]. Thus, global food prices can be linked to climate change and the vulnerability of rainfed agriculture, where the successful harvest depends on the arrival of seasonal rains at the right time and in sufficient amount, as shown in Table 4.

One may identify different types of droughts from an analytical perspective, although they are always characterized by insufficient water or water at the wrong time for agricultural purposes. First, there is unpredictable drought, which occurs when total precipitation is comparable to normal years, but the harvest is exposed to growth stress as a result of unpredictable, erratic, and uneven rainfall. Second, there is full-season drought, which occurs when overall precipitation patterns are much lower than in normal years and plants do not receive enough water. Third, there is terminal drought, which occurs when initially there is enough water for cultivation, but later the soil is exposed to a water deficit. Fourth, there is intermittent drought, which occurs when there is a short dry spell during the growing season and the harvest is exposed to drought only at one stage during growth.

Variability in rainfall generates dry spells almost every season and hence shorter periods of water stress during the growing season. Dry spells are manageable, and investments in water infrastructure can overcome these fluctuations, which may last from two to four weeks. Meteorological droughts, on the other hand, occurring on average once a decade in moist semiarid regions and up to twice per decade in dry semiarid regions, result in complete crop failure. When such droughts occur, they cannot be counteracted by agricultural water management, and other social coping strategies are necessary, such as food relief and grain banks. When the rain and the harvest fail, farmers have to buy their food for survival on the global market, where prices increase and fluctuate during periods of drought. Currently, food prices are extremely volatile, although in general food prices have decreased in absolute and relative terms over the past two decades. During 2007 and 2008, food prices increased rapidly worldwide. The price of wheat and maize doubled between

2003 and 2008. A major reason for this increase is the demand for biofuel, and it is estimated that between 2000 and 2007, agricultural production of biofuels contributed to an average global increase in cereal prices of approximately 30%. Although food prices have decreased since mid-2008, in 2009, they were still 30–50% higher on average than a decade earlier [26]. In March 2011, the food price index was 36% higher than in 2010 and remained close to the 2008 peak [27]. Between June 2010 and June 2011, prices in Ethiopia, for instance, increased by 86% for wheat and 64% for maize [27]. Importantly, there are huge differences, fluctuations, and increases in African domestic food prices even when global food prices decline or remain unchanged [27]. The previous stability in world food supply and generally declining prices were mainly due to irrigation, but this has had not only financial costs. Many irrigation systems have failed or resulted in environmental degradation and reduced water flows into wetlands [28]. Nevertheless, "irrigation will remain critical in supplying cheap, high-quality food, and its share of world food production will rise to more than 45 percent by 2030, from 40 percent today" [28].

8.1 Food Deficits and the Challenge of Feeding the Region's Poor

Food security, which refers to the availability of food and its accessibility to individuals, households, nations, and regions, is a major concern of the Basin states. Despite the production levels shown above, all Nile Basin countries, with the exception of Egypt, are unable to provide adequate nutrition to their population. Daily calorie availability per person in the Nile Basin countries (except Egypt) is below the 3,000 kcal per person threshold that is taken to imply the absence of undernourishment in a nation. About 140 million people in the Basin (or 34% of the population of the Basin states) are undernourished, with the level of severity varying from country to country. The Global Hunger Index, which is an aggregate proxy indicator combining undernourishment, child malnutrition, and child mortality statistics, shows that the situation with respect to hunger in three Nile Basin countries (Burundi, DR Congo, and Eritrea) is extremely alarming [8].

The challenge of feeding the Basin's population is expected to get even tougher in the coming years as it grows and as improvements in economic conditions introduce changes in lifestyle and diet. Clearly the Nile Basin countries must boost food production if they are to avert major food crises, which have the potential to erode and wipe out past gains in socioeconomic development. Under certain circumstances, enhancing regional and global trade could offer an opportunity for addressing deficits in national food production and attaining food security. In the case of the Nile Basin countries, however, food self-sufficiency has continued to decline, and the number of undernourished people has continued to rise as household incomes remain inadequate to afford purchased food. Much of the food consumed in the Nile Basin is produced within the Basin boundaries. In fact, most food is still grown in close vicinity to its actual consumers. Only Egypt imports a sizeable proportion of its annual nutrition requirements that reached 55% of the food requirements. The rural and urban poor typically spend between 50% and 80% of their income on food, and failure to provide sufficient food items at affordable prices could further marginalize this group. Thus, expanding production within each country to keep pace with population growth is important for protecting this vulnerable group (short of subsidizing the price of imported staple foods) [8].

9 Some Case Studies in the Nile Basin Countries

9.1 Rwanda

Rainwater occupies an important place in agriculture and in the national economy in Rwanda. Mean monthly statistics indicate that rainfall vary between 23.7 BCM and 36.9 BCM/year. The maximum monthly precipitation is in April. Most of the rainfall in Rwanda is lost through the evaporation at a percent of 82%; then, the remaining of the rainfall ranges between 4.3 and 6.6 BCM/year. Two rainy seasons in Rwanda allow two harvests a year. The first crop is harvests from June to September directly after the great rainy season. The second crop, from November to March, is threatened if the rainy season involves floods or if the great rainy season begins too early. The main crops are rice, cotton, tea, coffee, cocoa, Irish potato, sweet potato, banana, avocado, tobacco, sugarcane paddy, maize, green peas, soybean, vegetables, and fruits [29].

More than 80% of the population depends on agriculture, which contributes to 34% to the national GDP:

- Total land area = 24,700 km^2
- Arable land = 91% of land (2,294,390 ha)
  - Cultivated land (cash and food Crops) = 1,735,025 ha
  - Cultivated land (food crops; 2011) = 935, 32–34% of Rwanda's GDP
- 70% of exports
- Employment > 80% of population
- Provides 90% national food needs [29]

9.2 Burundi

About 90% of the population depends on agriculture for a living. Most agriculture consists of subsistence farming, with only about 15% of the total production marketed. An estimated 1,100,000 ha (2,718,000 acres), or about 43% of the total land area, is arable or under permanent crops; about 74,000 ha (182,800 acres) is irrigated. The average farm family plot is 0.8 ha (2 acres). Agriculture accounted for 50% of the GDP in 2010. Coffee and tea exports comprise the majority of foreign earnings; coffee alone accounted for 54% of exports of goods in 2001. Principal crops for local consumption are manioc, beans, bananas, sweet potatoes, corn, and sorghum. Production in 1999 included bananas, 1,511,000 tons, mostly for wine; manioc, 617,000 tons; sweet potatoes, 734,000 tons; beans, 227,000 tons; sorghum, 60,000 tons; corn, 129,000 tons; peanuts, 10,000 tons; and potatoes, 24,000 tons [30].

The primary export crop is coffee, chiefly of the Arabica variety. The government regulates the grading, pricing, and marketing of the coffee crop, and all coffee export contracts require approval. In 2001–2002, coffee production was 13,020 tons. Other export crops are cotton and tea. Seed cotton production was 3,000 tons, and cotton fiber production (after ginning) was about 1,000 tons in 1999. That year, tea production was 7,000 tons. Tea exports in 2001 of 8,706 tons represented 17% of total exports (up from only 4% during the 1980s); the government has been encouraging cotton and tea production in order to diversify exports. Palm oil is obtained from trees in plantations along the shore of Lake Tanganyika. Tobacco and wheat cultivated in the highland areas also yield some cash income [30].

The climate is of a temperate tropical type, with two rainy seasons. Eighty percent of the country's total area of 28,000 km^2 consists of an undulating plateau situated between 1,600 m and 2,000 m above sea level. Burundi is a landlocked country, and the nearest ports are located more than 1,500 km away in Dar es Salaam, United Republic of Tanzania, or Mombasa, Kenya. Nine in ten Burundians live in rural areas and depend almost exclusively on subsistence farming and livestock for their livelihood. Burundi is overwhelmingly rural. Its economy is based on agriculture. But the sector is struggling. In the 1970s and 1980s, agriculture was already in decline, and the situation worsened with the conflict that started in 1993. Food production is the dominant activity, and coffee and tea are the nation's biggest earners. They accounted for 8% of agriculture production but for no less than 90% of export earnings before the conflict started. The collapse of the international coffee and tea markets in the 1990s added a heavy burden to the economy [30].

From an agricultural point of view, soils on the plateau are generally good. In some areas, farmers struggle to produce crops because of the low fertility of the soils and the steep nature of the hills on which they plant. Common cropping practices are primarily based on crop associations – most frequently, beans, sorghum, cassava, millet, and maize. Almost without exception, farms also include livestock, mainly small animals. Common cropping practices are primarily based on crop associations – most frequently, beans, sorghum, cassava, millet, and maize. Figure 7 shows some rainfed agriculture activity in Burundi [30].

Fig. 7 Some agriculture farms in Burundi [30]

9.3 Congo

The area of The Congo Democratic Republic that belongs to in the Nile Basin is the smallest area in all Nile basin countries and does not exceed 4% of the Basin area, which represent about 0.1% of the area of Congo country which is the biggest country area in all Africa. This part belongs to the Semliki River which ended (lay out) in Lake Albert. The rainfed agriculture in Orientale and Ituri provinces, the only part located in the Nile Basin area, shares effectively in the republic agriculture economy. The main crops are rice, banana, cassava beans, groundnuts, maize, cotton, tobacco, rubber, cocoa, palm oil, coffee, and sugarcane.

9.4 Kenya

Agriculture is the mainstay of Kenyan economy, contributing to 24% of national GDP valued at KSh 342 billion (USD 4.5 billion) and another 27% indirectly valued at KSh 385 billion (USD 5.1 billion) in 2009 [28, 29, 31]. This sector in Kenya is large and complex, with a multitude of public, parastatal, nongovernmental, and private actors, accounting for 65% of Kenya's total exports [32–34]. Moreover, the sector employs over 40% of the total population and over 70% of the rural population. Agriculture also provides livelihoods (employment, income, and food security needs) for more than 80% of the Kenyan population [6]. Therefore, the sector is not only the driver of Kenya's economy but also the means of well-being for the majority of the Kenyan people [33]. In Kenya, the agricultural sector comprises six major subsectors, namely, (1) industrial crops, (2) food crops, (3) horticulture, (4) livestock, (5) fisheries, and (6) forestry. Figure 1 presents the contribution of the subsectors to agricultural gross domestic product (AGDP) and agricultural exports. The sector also covers the development of arid and semiarid lands (ASALs). Agricultural performance therefore influences the development of a number of other sectors and the livelihood of many people.

A robust agriculture sector can ensure food security and reduce poverty in Kenya, since most vulnerable groups like pastoralists, the landless, and subsistence farmers depend on agriculture as their main source of sustenance [35].

Of 576,000 square kilometers in total land area, only about 16% is of high and medium agricultural potential with adequate and reliable rainfall [31]. This potentially arable land is dominated by commercial agriculture with cropland occupying 31%, grazing land 30%, and forests 22% [33, 34]. The rest is ASALs not suitable for rainfed farming but rather used by ranchers, agropastoralists, and pastoralists. Kenya has seven distinct ecological zones, including Tropical Alpine, Upper Highland, Lower Highland, Upper Midland, Lower Midland, Lowland, and Coastal Lowlands. The country is also divided into three main production zones based on rainfall. In the high rainfall zone, the productive agricultural land can receive more than 1,000 mm of rainfall annually. The region occupies less than 20% of total productive agricultural land but has approximately 50% of the country's population. Using semi-intensive and intensive systems, this zone accounts for all the tea, pyrethrum, potato, coffee, vegetables, and nearly 75% milk production [34]. The medium rainfall zone receives between 750 mm and 1,000 mm of rainfall annually and occupies 30–35% of the country's land area [33]. It is home to about 30% of the population. Farmers in this zone keep cattle and small livestock and grow drought-tolerant crops. The low rainfall areas receive 200–750 mm of rainfall annually and are home to about 20% of the Kenyan population. They also contain 80% of the country's livestock and 65% of its wildlife [33]. Kenya's agriculture is mainly rainfed, making the sector vulnerable to weather variability which leads to fluctuations in production and incomes, especially in rural areas [35]. Overreliance on rainfed agriculture is one of the major causes of the country's food insecurity.

Farming in Kenya is usually on a small scale. About 75% of total agricultural output and 70% of marketed agricultural production come from farms around two to three hectares in size [36].

About 80% of the people in Kenya in the Nile Basin work in different types of agriculture activity, subsistence farming, livestock, and agropastoralism. Rainfed agriculture in western Kenya is supplemented with irrigation. Subsistence agriculture and cash crop cultivation form the backbone of the local economy. The main crops are tea, coffee, and sugarcane which have development authorities according to its impotency in supporting Kenya economy.

A smallholder system of agriculture production predominant in the Nile Basin region consists mainly of mixed farming on relatively small plots. Areas with adequate rainfall (101–152 cm) have more developed farms than those with limited and unreliable rainfall that suffer from alternate drought and flooding. Figure 8 shows some rainfed agriculture in Kenya.

9.5 Tanzania

Agriculture is an important sector of the Tanzanian economy in terms of food production, employment generation, production of raw material for industries, and

Fig. 8 Rainfed agriculture in Kenya [35]

generation of foreign exchange earnings. The agricultural sector produced about 26% of GDP (Economic Survey, 2008). Having a diversity of climatic and geographical zones, Tanzania's farmers grow a wide variety of food and cash crops as well as fruits, vegetables, and spices [37].

Agribusiness is still in its infancy in Tanzania, and commercial ventures are found mostly in traditional export crops such as coffee, tea, cotton, cashews, tobacco, and, on a much smaller scale, cloves and sisal. While arable land is estimated at 44 million hectares, only about 10 million hectares (23%) are currently under cultivation. The planted area has been stable for several years, so land expansion could be a major source of agricultural growth. Tanzania also has the third largest cattle herd in Africa, after Ethiopia and Sudan. But food production remains dominated by smallholders whose productivity is low. The average food crop productivity in Tanzania is 1.7 tons per hectare, whereas good management and optimal fertilizer use should result in yields of 3.5–4.0 tons per hectare. Only 15% of all farmers use fertilizers. The use of hand tools and the reliance upon traditional rainfed cropping methods and animal husbandry further hamper productivity (Fig. 9). Agricultural imports have been increasing, with food imports, including wheat, rice, and dairy products, taking the largest share (80%) of total merchandise imports. Since the 1999/2000 season, the food self-sufficiency ratio (SSR), which compares the volume of domestic food production against the food requirements of the country's population, has fluctuated between a low of 88% (2003/2004) and a high of 112% (2006/2007) [37].

9.6 Uganda

In Uganda, 85% of the population was engaged in agriculture production, contributing to 42% of the national GDP and 80% of the export earnings in 2005/2006. As early as 1994, a few commercial companies began deliberately engaging in organic agriculture. At the same time in Uganda, there was a general movement in the

Fig. 9 Rainfed agriculture in Tanzania [37]

agricultural sector toward developing sustainable agriculture as a means of improving people's livelihoods [21, 38].

By 2003, Uganda had the world's 13th largest land area under organic agriculture production and the most in Africa. By 2004, Uganda had around 185,000 ha of land under organic farming covering more than 2% of agricultural land, with 45,000 certified farmers. By 2007, 296,203 ha of land were under organic agricultural production with 206,803 certified farmers. This constitutes an increase of 359% in terms of number of farmers and 60% in terms of acreage, respectively, from 2002 to 2007 [21, 38].

According to IFOAM (International Foundation for Organic Agriculture Movements) [19, 20], the global market for organic foods and drinks is estimated to be around US$50 billion and increased by 10–20% annually between 2000 and 2007.

As a significant producer of organic products, Uganda benefits from an important source of export earnings and revenue for farmers. Certified organic exports increased from US$3.7 million in 2003/2004, to US$6.2 million in 2004/2005, before jumping to US$22.8 million in 2007/2008. In terms of price premiums and income for farmers, studies commissioned by the United Nations Environment Programme (UNEP) and United Nations Conference on Trade and Development (UNCTAD) indicate that in 2006, the farm gate prices of organic pineapple, ginger, and vanilla were 300%, 185%, and 150% higher, respectively, than conventional products [21, 38].

Through organic farming, Uganda not only gains economically; it also contributes to mitigating climate change, as greenhouse gas (GHG) emissions per hectare are estimated to be on average 64% lower than emissions from conventional farms. Various studies have shown that organic fields sequester 3–8 tons more carbon per hectare than conventional agriculture [21, 38].

The agricultural sector is dominant in Uganda's economy. The agricultural sector employs 82% of the workforce, accounts for 90% of export earnings, and provided 44% of GDP in 1999. Moreover, the farmers in Uganda's 2.5 million smallholdings and scattered large commercial farms provide the majority of their own and the rest of the country's staple food requirements. Uganda is able to rely on agriculture due to the country's excellent access to waterways, fertile soils, and,

Fig. 10 Rainfed agriculture in Uganda [38]

relative to many other African nations, its regular rainfall, although it does still suffer from intermittent droughts such as in 1993/1994 [21, 38].

Uganda's key agricultural products can be divided into cash crops, food crops, and horticultural produce. The most important cash crops are coffee, tea, cotton, tobacco, and cocoa. Uganda is second only to Kenya as Africa's largest producer of tea, exporting US$17.06 million of tea in 1996 and $39 million by 1998. Unmanufactured tobacco exports provided US$9.5 million in 1998, over 25% more than in 1996. The export of cocoa beans hit a recent high in 1996 with US $1.07 million in export receipts, but this had declined to $0.87 million in 1998. The primary food crops, mainly for domestic consumption, include plantains, cassava, maize, millet, and sorghum. Total cereal production was 1.76 million metric tons in 1998, which provided US$17.82 million of exports in 1998. This gain was in part negated as imports of cereals were $30.9 million in the same year. The more recent development of cultivating horticultural produce includes fresh flowers, chilies, vanilla, asparagus, and medicinal plants. At the beginning of 2001, it is unclear how well horticultural production will prosper, but it does indicate the economy's potential diversity. The fact that vanilla production is the third largest in Africa, providing US$930,000 in export receipts in 1998, is a success in itself [21, 38].

The economy of northeast Uganda is dominated by pastoralism (cattle farming). Although agricultural production is apparent in some areas, this is normally a mixture known as "agropastoralism" (integrated cattle and crop farming). It should be noted that pastoralism is in decline due to the constant cattle raids by guerrilla groups such as the Lord's Resistance Army based in southern Sudan, as well as government and aid agency intervention which encourages the fencing-off of land to discourage the traditional free-roaming of cattle (Fig. 10) [21, 38].

9.7 Ethiopia

The agricultural sector greatly influences economic performance in Ethiopia. About 11.7 million smallholder households account for approximately 95% of agricultural GDP and 85% of employment [37]. About 25% of rural households earn some income from nonfarm enterprises, but less than 3% rely exclusively on income from such enterprises. With a total area of about 1.13 million km^2 and about 51.3 million hectares of arable land, Ethiopia has tremendous potential for agricultural development. Only about 11.7 million hectares of land, however, is currently being cultivated, just over 20% of the total arable area. Nearly 55% of all smallholder farmers operate on one hectare or less. The agricultural sector accounts for roughly 43% of GDP and 90% of exports. Cereals dominate Ethiopian agriculture, accounting for about 70% of agricultural GDP. Livestock production accounts for about 32% of agricultural GDP, and draught animal power is critical for all farming systems. Over the past decade, cereal production has more than doubled to nearly 15 million tones, as a result of horizontal expansion and increased yields. Nevertheless, food security remains a critical issue for many households, and for the country as a whole. Moreover, expansion of the cropped area to more marginal lands has led to severe land degradation in some areas. Ethiopian agriculture is dominated by a subsistence, low input–low output, rainfed farming system. The use of chemical fertilizer and improved seeds is quite limited despite government efforts to encourage the adoption of modern, intensive agricultural practices. Low agricultural productivity can be attributed to limited access by smallholder farmers to agricultural inputs, financial services, improved production technologies, irrigation and agricultural markets, and, more importantly, poor land management practices that have led to severe land degradation. Ethiopia has one of the highest rates of soil nutrient depletion in sub-Saharan Africa. Estimates suggest that the annual phosphorus and nitrogen loss nationwide from the use of dung for fuel is equivalent to the total amount of commercial fertilizer applied. Land degradation is further exacerbated by overgrazing, deforestation, population pressure, and inadequate land-use planning [37].

In the main agricultural regions of Ethiopia, there are two rainy seasons, the meher and the belg seasons, and consequently there are two crop seasons.

Five major cereals (teff, wheat, maize, sorghum, and barley) are the core of Ethiopia's agriculture and food economy, accounting for about three-fourths of the total area cultivated, 29% of agricultural gross domestic product (GDP) in 2005/2006 (14% of total GDP), and 64% of calories consumed. Cereals were grown on 73.4% of the total area cultivated by a total of 11.2 million farmers. Together, these holders produce a yearly average of 12 million tons of cereals. Teff accounts for 28% of the total cereal area cultivated, while maize comprises 27% of total annual cereal production, but only 19% of cereal area cultivated. After cereals, the second most important crop group (in terms of acreage) is pulses. In 2004/2005–2007/2008, 6.4 million holders grew pulses on 12.4% of the total area cultivated. Total pulse production averaged 1.5 million tons per year. Oilseeds form the third most important crop group. In 2004/2005–2007/2008, they were cultivated on 6.9% of the total area cultivated by 3.1 million holders who produced an average of 0.5 million tons of oilseeds yearly. Coffee is a major cash crop, accounting for 3.8% of GDP (and 19 and 35% of the quantity and value of exports, respectively, in the period) but occupied only 2.7% of total area cultivated (i.e., 306,000 ha). Chat, another stimulant crop, was cultivated by 2 million farmers on 1.3% of the total area

Fig. 11 Some rainfed agriculture in Ethiopia [37]

cultivated, and it accounted for 5% of total export earnings. Vegetables and root crops together were cultivated on 281,000 ha comprising 2.6% of the total area cultivated (Fig. 11) [37].

About 12 million smallholder households account for approximately 95% of agricultural GDP and 85% of employment. With a total area of about 1.13 million km^2 and about 51.3 million hectares of arable land, Ethiopia has tremendous potential for agricultural development. Currently, just over 20% being cultivated. Nearly 55% of all smallholder farmers operate on one hectare or less. The agricultural sector accounts for roughly 41% of GDP, and 90% of exports (2009/2010) [37].

9.8 South Sudan and Sudan

The main land cover types of South Sudan in the Nile Basin are forest (42.5%), shrubland (33.7%), and cropland (11.8%). Mosaic vegetation covers 2.9% of the land, while grassland covers 1.5%. Wetlands account for 7.2% of the land which is part of the Sudd swamp, one of the largest swamps. Its area varies from 8,000 km^2 in the dry season to as much as 40,000 km^2 in the wet season [39, 40].

Most of the land in the Basin area of South Sudan is covered with woody savannas and savannas, albeit with some changes from year to year. Savannas covered about 46% of the land in both 2001 and 2009, but woody savannas declined by 1.6% over the same period. Grasslands increased to 4.7% from 2.5% in 2001. Forests, crops, cropland and natural vegetation, and built-up or barren lands each covered one percent or less of the land. Each of these land classes decreased by 0.7% or less between 2001 and 2009. Shrublands and wetlands each experienced a small increase (0.2 and 0.5%, respectively) over the same timeframe. Overall, however, the major land cover types remained largely unchanged [22–42].

Much of Sudan is arid, and there is high scarcity of water that limits the development of the country; therefore, water resources are considered a high priority for the nation [38]. More than half, 55.3%, of the land is classified as barren. Forest (14.9%), grassland (12.8%), mosaic vegetation (8.3%), and cropland (6%) mostly make up the other half. Shrubland accounts for a marginal amount of land – just 2.4%. Although only 0.2% of the land is classified as water, Sudan is where the White and Blue Niles meet before flowing into the main Nile.

The northern part of Sudan forms the sector of the Nile Basin where the White Nile flowing from the Equatorial Lakes region and the Blue Nile from the Ethiopian Highlands meet. It is at this point that the capital city, Khartoum, is located. The analysis indicates only minor variations in the dominant land cover types. In both 2001 and 2009, built-up or barren lands covered much of the northern part of the Basin (54.2 and 50.3%, respectively), including urban areas such as Khartoum and other cities. The approximate 4% decline of this land cover type appears to have given way to shrubland or grassland. Shrublands increased from 3.6% in 2001 to 5.3% in 2009, and grasslands increased 4.9% from 20% in 2001 to 24.9% in 2009. Crops cover 3% of Sudan's portion of the Nile, a 0.2% increase from 2001. Although there has only been a slight change in percentage, crops have increased in the southeastern part of the Basin between 2001 and 2009 but have decreased in the southwest. The cropland and natural vegetation land cover class did decrease from 2.7% in 2001 to 1.1% in 2009. Wetlands, woody savannas, and savannas each decreased by less than 1% from 2001 to 2009. Any forest cover in Sudan cannot be identified from the MODIS imagery [39, 40, 42].

10 Conclusions and Recommendations

About 437 million people in the Nile Basin countries and 238 million within the Basin itself reside in rural areas and depend mainly on agriculture for their nutrition and livelihoods. Growth of agricultural production is, therefore, key to food security and poverty reduction, yet it remains a largely subsistence activity, with production lagging behind population growth. As local production of food falls short of local demand, the Basin countries are net importers of food. A considerable proportion of the Basin population does not, however, receive sufficient nourishment. There are two broad types of production systems in the Nile Basin: rainfed crop and livestock production systems and irrigated agriculture. The former is vulnerable to impacts of climate variability and change and is characterized by subsistence production and low inputs and yields. The latter, especially on a commercial scale, has high productivity and improved water-use efficiency, but there are a number of schemes in the Basin where yields are still low. Intra-basin trade in agricultural products has the potential to promote rural development, enhance regional food security, and foster regional integration. However, trade volumes in primary agricultural commodities between Nile Basin countries are low because none of the riparian countries produce sufficient surplus to sustain high-volume intra-basin trade. The opportunity for enhancement of regional integration through trade therefore remains largely unutilized, despite the improving climate for regional trade brought about by the creation of regional trade bodies such as EAC (East African Community) and COMESA (Common Market for Eastern and Southern Africa).

To produce sufficient food to feed the Basin population and generate surplus for regional trade and enhancement of rural household incomes, it is recommended that the Nile Basin countries implement a coordinated set of measures targeting the multiple constraints affecting the agricultural production sector, which include:

- Floods and failing rains
- Vigorous weeds
- High disease and pest prevalence
- High cost of farm inputs such as fertilizer and pesticides
- High postharvest losses
- Weak extension services
- Lack of credit
- Inadequate information on market opportunities.

The present dominance of smallholder rainfed subsistence farming in the upper riparian countries is likely to persist to 2030 and beyond. It is therefore important to improve the productivity of this farming system to be able to improve rural livelihoods and enhance national and regional food security. From a water management perspective, the important interventions should include:

- Increasing investment in irrigation development in the Nile Basin countries. In the downstream countries, this should focus on improving water-use efficiency, while in the upstream countries, it should focus on improving efficiency of existing irrigation systems and expanding the land under irrigation.
- Improving scheme management and agricultural productivity in the large smallholder irrigation schemes in the downstream countries so as to triple agricultural production without additional water demands.
- Increasing investment in rainwater harvesting and small-scale irrigation in upstream countries to increase the resilience of rainfed agriculture to climate-related shocks.
- Increasing investment in watershed management in upstream countries to reduce soil erosion and to increase water availability, especially in mixed highland smallholder subsistence farming systems.

As production rises and agricultural commodity trade within the region continues to benefit from progressive reduction in tariffs, the struggle to increase trade should shift to deal with the many nontariff barriers between countries.

References

1. United Nations World Water Assessment Programme (UN WWAP) (2014) The United Nations world water development report 2014: water and energy. UNESCO, Paris
2. http://www.iwmi.cgiar.org/Publications/Working_Papers/working/WOR20.pdf

3. Stockholm Environmental Institute (SEI) (2011) Understanding the Nexus. Background paper for the Bonn 2011 Nexus conference – The water, energy and food security Nexus: solutions for the green economy
4. African Water Atlas (2010) United Nation Environment Programme, ISBN:978-92-807-3110-1
5. FAO (2005) Land and water development division. AQUASTAT information system on water and agriculture: country profile- Sao Tome and principe. Food and agriculture organization of the United Nations. http://www.fao.org/nr/water/aquastat/countries/sao_tome_prn/indexfra.stm
6. FAO (2005) FAOSTAT (food and agriculture organization statistics). http://www.fao.org/statistics/en/
7. FAO (Food and Agriculture Organization of the UN) (2010) Agricultural policy frameworks in Kenya. Food and agriculture policy decision analysis. http://www.fao.org/fileadmin/templates/fapda/KenyaPolicy_Report.pdf
8. NBI (2014) The State of the river Nile basin 2012. http://www.nilebasin.org/
9. UNECA (2007) Africa review report on agriculture and rural development. United nations economic commission for Africa. http://www.un.org/esa/sustdev/csd/csd16/rim/eca_bg2.pdf
10. IWMI (2009) http://www.iwmi.cgiar.org/Publications/CABI_Publications/CA_CABI_Series/Rainfed_Agriculture/Protected/Rainfed_Agriculture_Unlocking_the_Potential.pdf
11. SEDAC (2010) Gridded population of the world: future estimates. Socioeconomic data and applications center (SEDAC); collaboration with CIESIN, UN-FAO, CIAT. http://sedac.ciesin.columbia.edu/gpw
12. UNECA (2009) The transport situation in Africa. Sixth session of the committee on trade, regional cooperation and integration. 13–15 October 2009. Economic commission for Africa, Addis Ababa, Ethiopia. http://www.uneca.org/eca_resources/major_eca_websites/crci/6th/TransportSituationinAfrica.pdf
13. CIESEN (2005) Center for international earth science information network (CIESIN), Columbia University; and Centro Internacional de Agricultura Tropical (CIAT), 2005, Gridded Population of the World Version 3 (GPWv3). Palisades, NY: Socioeconomic Data and Applications Center (SEDAC), Columbia University. http://sedac.ciesin.columbia.edu/gpw
14. CIESIN (2007) National aggregates of geospatial data: population, landscape and climate estimates, v.2 (PLACE II), Palisades. Center for international earth science information network (CIESIN), Columbia University, 2007. http://sedac.ciesin.columbia.edu/place/. Accessed 16 Sept 2010
15. Lehman J (2009) Lake Victoria. In: Dumont HJ (ed) The Nile: origin, environments, limnology and human use. Springer Science, Dordrecht
16. UNEP and WRC (2008) Assessment of transboundary freshwater vulnerability in Africa to climate change, United Nations environment programme and water research commission. http://www.unep.org/dewa/assessments/ecosystems/water/Assessment_of_Transboundary_Freshwater_Vulnerability_revised.pdf
17. UNEP (2002) Africa environment outlook: past, present and future perspectives. United Nations Environment Programme. Earthprint: UK
18. IFOAM, international Federation of Organic Agriculture Movement (2004) Organic farming what is it? http://www.ifoam.bio/
19. IFOAM (2007) Organic markets in Africa. (authored by Gunnar Rundgren and Peter Lustig). Bonn. http://www.ifoam.bio/
20. IFOAM (2014) Website. http://www.ifoam.org/organic_facts/food/
21. Hoff H, Falkenmark M, Gerten D, Gordon L, Karlberg L, Rockström J (2009) Greening the global water system. J Hydrol 56:199–211
22. FAO (1996) Report of the world food summit. FAO, Rome
23. Cook S, Fisher M, Tiemann T, Vidal A (2011) Water, food and poverty: global- and basin-scale analysis

24. World Food Council (1988) Towards sustainable food security: critical issues, report by the Secretariat, 14th Ministerial Session, Nicosia, Cyprus, 23–26 May. e analysis', Water International 26(1):1–16
25. World Bank (1986) Poverty and hunger. World Bank, Washington, DC
26. Havnevik K (2011) Grabbing of African lands for energy and food: implications for land rights, food security and smallholders. In: Matondi PB, Havnevik K, Beyene A (eds) Biofuels, land grabbing and food security in Africa. Zed Books, London, pp. 20–43
27. Food Price Watch Faurès J-M (2007) Reinventing irrigation. In: Molden D (ed) Water for food, water for life: a comprehensive assessment of water management in agriculture. International Water Management Institute, Colombo and Earthscan, London, pp. 353–394. (2011), Food Price Watch April 2011, World Bank, Washington DC
28. Faurès J, Santini G, de Villemarceau AN (2008) A livelihood approach to water interventions in rural areas and implications for multiple use systems' in Multiple-use Water Services. In: Butterworth J, Keitjizer M, Smout I, Hagos F (eds) Proceedings of an international symposium held in Addis Ababa, Ethiopia, 4–6 November 2008. MUSGroup
29. Mbonigaba Muhinda JJ (2013) Rwanda agricultural sector and its impact on food security and economy, workshop on Asian lessons and agriculture transformation in Rwanda, Kigali, 31 Jan 2013
30. UNEP (2013) Adaptation to climate-change induced water stress in the Nile basin: a vulnerability assessment report. Division of Early Warning and Assessment (DEWA), United Nations Environment Programme (UNEP), Nairobi, Kenya
31. Makurira H (2010) Water productivity in rainfed agriculture: redrawing the rainbow of water to achieve food security in rainfed smallholder systems. PhD thesis's, The Netherlands
32. GoK (Government of Kenya) (2009) Agricultural Sector Development Strategy (ASDS). http://www.kecosce.org/downloads/AGRICULTURE_SECTOR_DEVELOMENT_STRATEGY_2009_2025.pdf
33. GoK (Government of Kenya) (2010) Agricultural sector development strategy-medium-term investment plan: 2010–2015. http://www.resakss.org/sites/default/files/blog/2011/08/kenya-medium-term-investment-plan-2010-2015.pdf
34. GoK (Government of Kenya) (2011) Medium-term expenditure framework 2011/12–2013/14. Report for the agriculture and rural development sector. Nairobi: Government printers. https://www.google.co.ke/search?q=medium+term+expenditure+framework+agriculture+sector&oq=medium+term+expenditure+framework+agriculture+sector&aqs=chrome.69i57.17861j0j8&sourceid=chrome&espv=210&es_sm=91&ie=UTF-8
35. Alila PO, Atieno R (2006) Agricultural policy in Kenya: issues and processes. A paper for the future agricultures Consortium Workshop, Institute of Development Studies, 20–22 March 2006. http://www.fao.org/fileadmin/user_upload/fsn/docs/Ag_policy_Kenya.pdf
36. UNEP (United Nations Environment Programme) (2014) Green economy assessment report: Kenya. http://www.unep.org/greeneconomy/portals/88/documents/KenyaGEassessment.pdf
37. UNEP (2010) Africa Water Atlas, Division of Early Warning and Assessment (DEWA), 2010, United Nations environment programme, ISBN:978-92-807-3110-1. United Nations Environment Programme (UNEP). Nairobi, Kenya
38. UNEP (2015) Green economy sector study on agriculture in Kenya. http://www.unep.org/publications/
39. Ahmad AM (2008) Post-Jonglei planning in southern Sudan: combining environment with development. Environment and Urbanization. 2008 20:575. Sage publications on behalf of International Institute for Environment and Development (IIED). http://eau.sagepub.com/content/20/2/575.full.pdf+html. Accessed 6 March 2013
40. Lamberts E (2009) The effects of Jonglei Canal operation scenarios on the Sudd swamps in Southern Sudan. MS Thesis. University of Twente, Netherlands. http://essay.utwente.nl/59163/

41. Sultan B, Baron C, Dingkuhn M, Sarr B, Janicot S (2005) Agricultural impacts of large-scale variability of the West African monsoon. Agr Forest Meteorol 128(1–2):93–110
42. NBI (2010) Country profiles: Sudan. Nile Basin Initiative (NBI), Entebbe. http://www.nilebasin.org/newsite/index.php?option=com_content&view=article&id=137%3Acountry-profiles&catid=35%3Anbi-countryprofiles&Itemid=67&lang=en
43. Ingram K, Roncoli M, Kirshen P (2002) Opportunities and constraints for farmers of West Africa to use seasonal precipitation forecasts with Burkina Faso as a case study. Agr Syst 74:331–349
44. De Rouw A (2004) Improving yields and reducing risks in pearl millet farming in the African Sahel. Agr Syst 81:73–93

Impacts of the Upper Nile Mega Projects on the Water Resources of Egypt

Alaa El din M. Elzawahry and Hesham Bekhit M. Bekhit

Abstract This chapter explores the potential impacts of the River Nile mega projects on water resources of Egypt. The addressed mega projects are located on the White Nile, the Blue Nile, and the Main Nile up to Lake Nasser. The mega projects are mainly categorized as Irrigation; Canalization (streaming); and Power generation projects (Dams). The impacts on the water resources of Egypt were thoroughly investigated in different but interrelated dimensions. The main impact is the shortage of water reaching the most arid zone on the Nile in Egypt. Such shortage of water will create a chain reaction influencing at large all the environmental activities in Egypt (total environmental impact). The impacts include crop and fish production and farmers income, present and future reclaimed land (other developments), salt water intrusion, soil salinity, supply intakes and intakes for water treatment plants, main canals and rayahs, ecological imbalance, tourism industry, health risks, generation of hydropower, Dam failure impacts, and socio-economic impacts.

Keywords GERD impacts, Mega projects impacts, Nile River

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A.E.d.M. Elzawahry (✉) and H.B.M. Bekhit
Irrigation and Hydraulics Department, Faculty of Engineering, Cairo University, Giza, Egypt
e-mail: alaa.zawahry@gmail.com; heshambm@cu.edu.eg

A.M. Negm (ed.), *The Nile River*,
Hdb Env Chem (2017) 56: 503–530, DOI 10.1007/698_2016_113,

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1 Background

The Nile River is a major regional resource and a global asset. The Nile River is the world's longest river it travels more than 6,700 km. The river is shared by 11 countries: Burundi, Democratic Republic of Congo, Egypt, Eritrea, Ethiopia, Kenya, Rwanda, South Sudan, Sudan, Tanzania, and Uganda [1]. The basin covers about 3 million km^2 which presents one tenth of Africa's land mass. For millennia the Nile River has played a central role in human settlement and in the development of a rich diversity of cultures and livelihoods. The basin includes world class environmental assets, notably Lake Victoria, the second largest freshwater body in the world, and the vast wetlands of the Sudd area in Southern Sudan [2].

Although the Nile is one of the world's most famous rivers, its average annual natural discharge at Aswan is just 84 bcm^3 (1900–1954), while the Congo River, for example, discharges some 1,400 bcm^3. The Nile loses a vast amount of water through evapotranspiration in the swamp areas in its upper reaches and by evaporation during its 3,000-km course through the arid lands of Sudan and Egypt [1].

2 Review of the Nile River Current Conditions

The Nile River consists of several tributaries and streams. The main streams are the White Nile, which originates from the Great Lakes region of East Africa, the Sobat, the Blue Nile (Abbay), and the Atbara (Tekeze) that flow from the highlands of Ethiopia. The most remote source is the Kagera River, which winds its way through Burundi, Rwanda, Tanzania, and Uganda into Lake Victoria. The average natural annual flow at Aswan is in the order of 84 bcm. If this yield is divided into water units, each unit equivalent to 12 bcm, then the annual yield at Aswan would be composed of 7 units, which can be summarized as follows:

Bahr el Jebel downstream the Suddavb	1 unit
Sobat River	1 unit
Blue Nile River	4 units
Atbara River	1 unit
Main Nile at Aswan	*7 units*

It is obvious that the main contribution (84%) is attributed to Ethiopian plateau main tributaries named: Abbay, Tekeze, and Sobat (Baro-Akobo). Such major contribution makes the impact of any development in these areas severe on Egypt. That is mainly because Egypt is classified as one of the most arid countries in the world and is downstream of development. The country's water resources are mainly limited to the Nile River that provides Egypt with 97% of its water requirements. The remaining 3% comes from ground water and rainfall. Consequently, due to such dependency on the river, the proposed large scale projects in the Nile basin will cause tremendous difficulties for the country.

3 Overview of the Potential Development Projects

The potential development projects can be classified into several areas, namely

- Hydropower production
- River basin management and tapping water losses
- Agriculture development
- Watershed management
- Navigation and regional trade.

Hydropower or electricity generation is a critical ingredient in all sectors of the national economy. Several small to large hydropower dams are either proposed or already under construction within the basin. For example, Ethiopia is taking actions to make use of the hydropower potential in different river basins in Ethiopia in general, and in the Blue Nile Basin in particular. In that context, the Ethiopian government submitted to the Nile Basin Initiative (NBI) its national projects of constructing four large dams on the main Blue Nile. The characteristics of these dams are presented in Table 1.

In 2011 and just few weeks after the Egyptian revolution, Ethiopia unilaterally announced the construction of Grand Ethiopian Renaissance Dam (GERD). Ethiopia did not send Egypt nor Sudan prior notification regarding dam construction or any information about the design of the dam or an environmental assessment study. The GERD dam was not one of the dams that were submitted to NBI (Table 1), however, GERD is currently constructed in the same location where Border Dam was proposed but with significant changes in the specifications of the dam. The gravity dam will be 145 m in height, and 1,800 m long. Its reservoir will have a storage capacity of 74 BMC and surface area of 1,561 km^2 at a normal elevation of 640 m. To achieve the desired storage, a rock-fill saddle dam will be constructed at the site. The rock-fill saddle dam will be 5 km long and 50 m high. As one example of the Mega projects taking place in the region, the impact of GERD dam will be thoroughly investigated below.

Table 1 Main characteristics of the proposed Ethiopian dams [11]

Dam name	Total volume (bmc)	Dam height (m)	Hydropower (MW)
Karadobi	40.2	250	1,600
Beko Abo	37.5	285	2,100
Mandaya	49.2	200	2,000
Border	14.5	90	1,400
Total	141.4		7,100

River basin management in the Nile Basin presents challenges that are national, regional, and trans-boundary. The swamps of the Sudd are responsible for the loss of much of the Nile outflow from Lake Victoria. At present only half the inflow of the Bahr el Jebel or White Nile at Mongalla emerges from the tail of the swamps. The remainder spills from the river into permanent and seasonal swamps and subsequently evaporates.

Several projects were proposed to tap these losses. For example, a project to reduce water losses in the swamps of Machar and Sobat Basin is proposed. The Sobat River is formed by the junction of two main branches: the Baro and the Pibor. The Baro is considered to be the principal feeder to the Sobat as it contributes at its mouth an average of 9.530 bcm/year for the period (1929–1967), while the Pibor contributes 3.370 bcm yearly. At present the Baro losses are about 4 bcm in the adjacent swamps between Gambella and the junction of the Baro and Pibor. Studies have shown that the best solution to regulate the Baro River and reduce its losses is to release uniform discharge all over the year below the capacity of the natural cross-section at Gambella, which can be achieved by storing the water upstream of Baro River and regulating the flow.

A second project is proposed to reduce water losses from the swamps of Bahr el Ghazal basin area. Bahr el Ghazal basin area is approximately 526,000 km^2. The swamp areas within the basin were estimated to be 40,000 km^2. The average annual rainfall that falls on this basin is about 0.90 m. Bahr el Ghazal consists of several rivers including Bahr el Ghazal River, Lol River, Jour River, Bongo River, Tong River, and Yei River. The total annual discharge from these rivers based on actual measurements on some branches is about 16.00 bcm. Unfortunately, most of the water loss takes place in the Sudd wetlands. The total water that reaches the White Nile at the mouth of the Bahr al-Ghazal in the Lake Nou is only 0.5 bcm/year.

In May 1974 the Egyptian and Sudanese governments agreed to construct Jonglei Canal project; as another example. The project started, but due to civilian war, the project stopped and never completed to this day. The main idea of the project is to construct a canal east of the Sudd swampy area. The main objective of this canal is to divert part of the large water losses at Bahr al Jabal above the Sudd region to a point on the White Nile after the swamp area, and accordingly bypass the swamps and carry part of the waters directly to the main channel of the river. However, the project has been through a lot of debate between pros and cons against the canal. Some see it as a boost for the area economically, socially, and culture-wise besides the water savings. Others have environmental concerns that the size of the swampy area will be reduced, which will adversely affect the grazing activities of the local tribes living in the area. This project will be discussed in detail as an example of River basin management and their anticipated impacts.

The agricultural sector is the main sector that largely contributes to Nile Basin countries gross domestic product (GDP), employment, and food security. On the other hand, agriculture takes the lion share from Nile water as it is also the largest water consuming sector in the Nile Basin. All the Nile countries have ambitious plans for agricultural development.

For example, based on the Ethiopian River basin master plans, the aggregate irrigation potential (large, medium, and small) has been estimated at 3.7 million hectare (ha) of which 1.5 million ha is considered in the Nile basin [3, 4]. The currently developed land acreage is around 193,224 ha, with 81,119 ha under a small scheme (less than 200 ha) and 112,105 under a medium and a large scale (more than 200 ha).

Sudan also has optimistic plans to develop irrigation schemes such as Rahad II, Kenana, and South Dinder in association with increased storage that will be provided by increasing the reservoir capacities in Sudan and Ethiopia.

In addition, all the other riparian countries have their own ambitious plans to add agricultural development projects. Therefore, the main challenge that is facing the Nile Basin countries is growing. Most countries are planning for more development projects which require more water, but water is limited and the demands are growing fast. Such conditions create potential for conflict. Therefore, innovative policies and agricultural practices are needed. For example, relying more on rain-fed practices in upstream Nile countries is considered a great potential to increase their agricultural success [5]. Several actions need to be taken to allow for the creation of better water and land management practices in these areas to reduce poverty and increase productivity. Unilateral and unwise development could destroy the ecosystems which are vital to human survival and must be protected in harmony within the riparian countries. To complete the picture, a quantitative assessment of the impacts of some potential agricultural development on downstream countries will be illustrated in the coming section.

Using the river Nile for navigation is common in Sub-Sahara, small wooden boats have been used to transport goods and individuals within the local boundaries, and cross border navigation is valid between Egypt and Sudan and also in Lake Victoria. However, the existing navigation system in the Nile is very limited. Nevertheless, there is a huge potential for opening new regional trade corridors in Africa starting from Lake Victoria all the way up to the Mediterranean Sea, which will establish a longer trade route further South till Cape Town, in South Africa. Therefore, The Presidential Infrastructure Champion Initiative (PICI) nominated Egypt to be in charge of managing a river transport project from Lake Victoria to the Mediterranean Sea in cooperation and coordination with all countries benefiting from the project. This regional project is entitled "***The Navigational Route from Lake Victoria to the Mediterranean Sea, via the River Nile***." The project's benefits and positive impacts are not only limited to the Nile countries, but also extend to the entire region.

Egypt organized a workshop to announce the official launch of the regional project on Friday June 7th, 2013. But the project is still struggling at the first stage. Promoting such a mega project will positively alter the economic situation in all riparian countries.

4 Selected Projects for Detailed Analysis

4.1 Detailed Analysis of One of Hydropower Mega Project (Case of GERD Dam)

4.1.1 Deterministic Approach

This section is part of a detailed study with the objective of assessing the impacts of the GERD on the High Aswan Dam (HAD) using the historical time series records of the Nile. A comprehensive model of the Eastern Nile system (GERD Nile-DST) was used to assess the impacts of GERD. The simulation model encompasses the Eastern Nile system. The main characteristics of GERD were taken based on the final report of International Panel of Experts (IPOE).

The Impact of GERD on Egypt was assessed under different conditions taking into consideration different hydrologic cycles and different operation rules. A baseline which simulates the current condition (without the GERD) was established first for comparison with the case after GERD. The results of base case simulation indicate that Egypt's water and energy sectors are vulnerable to severe impacts during the drought period. More specifically, Egypt is expected to experience water shortage and HAD turbines will be forced to shut down should a drought similar to that of the 1980s reoccur.

The impacts on Egypt will be more severely pronounced after the construction of GERD dam during both stages of filling and operation of the dam. The filling of GERD was assessed assuming two cases of incoming flow records. The first case assumed an average or normal period similar to the period of 1912, and the second case assumed below average flow (drought period) similar to the period of 1980s. The assessment was conducted using a 6 year filling rule as announced by the Ethiopian government and also sensitivity for the number of filling years were carried out. Figure 1 shows the results of filling simulations. The results indicated that the filling of GERD will have very significant impacts for the Egyptian water and energy sectors. If filling occurs during the normal condition (1912), water shortages could reach up to 34.4 bcm, spread over three years; compared to no shortage for the baseline. The water sector impacts are most devastating if filling occurs during periods of below average river flows. Specifically, under these conditions and for the 1980 hydrologic period, water shortages could reach up to 68 bcm, spread over 3 years. The impact of GERD filling on the Egyptian energy sector is equally significant, with energy reductions reaching up to 32% of the baseline. As depicted from Table 2, increasing the filling period will result in a proportional decrease in water shortage and it depends on the hydrological cycle.

Assessments combining the Ethiopian filling rule and regulation policy for the period (1912–2011) were performed for two scenarios. The first scenario assumes that the filling started with a hydrological cycle similar to the historic cycle of 1912, whereas the second scenario assumes that the filling started with a hydrological cycle similar to the historic cycle of 1980. Table 3 summarizes the results of the two

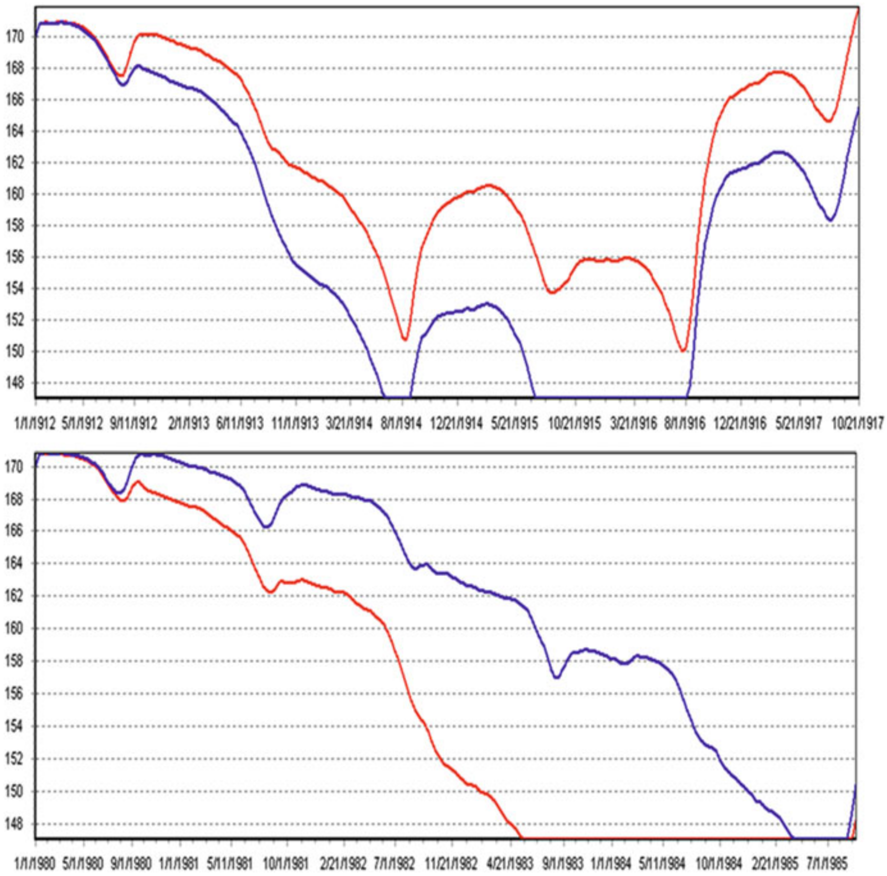

Fig. 1 Levels of GERD and HAD with different filling rules ((**a**) Case of average flow, (**b**) Case of below average)

Table 2 HAD impacts for filling rules and sequences; different filling periods

Filling period	HAD annual energy reduction (GWH)	Energy reduction (%)	HAD elevation drawdown (m)	Additional HAD shortage to No GERD case (bcm)
6 years	1,550	32	5.1	35
7 years	1,350	24.8	5	29
9 years	1,526	24.7	5	21
12 years	1,630.0	24.7	4.3	13.6

cases. The results confirm that while the GERD would benefit Ethiopia, it would cause unacceptably negative impacts to the Egyptian water and energy sectors. Water shortage could reach up to 138.8 bcm spread over 14 years, compared to about 44.6 bcm, spread over 4 years for the baseline.

Table 3 Impacts for long-term regulation rules and sequences; different hydrological conditions

Scenario	GERD annual energy (GWH)	HAD annual energy (GWH)	Energy reduction (%)	Shutdown years of HAD turbines	HAD shortage (bcm)
1912 W/O GERD	–	7,121.6	–	13.08	44.6
1912 W GERD	14,641.8	5,147.9	27.7	29.92	138.8
1980 W/O GERD	–	7,330.3	–	11.47	39.7
1980 W GERD	14,581.8	5,643.9	23	24.58	150.1

It should be noted that HAD level/volume will drastically decrease after the filling period which necessitates a long period for the system to recover. The alternative GERD sizes demonstrate that smaller GERD heights generally imply less severe impacts for the Egyptian water shortage and energy production.

4.1.2 Stochastic Approach

This section is part of a study with the objective of assessing the impacts of the GERD on the High Aswan Dam (HAD) [6]. The study used stochastically generated data based on the historical time series, and takes into consideration the announced GERD storage capacity and the associated filling and operation rules. In addition, the study investigates some proposed measures that aim to reduce the identified negative impacts, including reverting to the original dam size of 14.5 bcm that was named "Border Dam."

Stochastic or probabilistic approaches enable variation and uncertainty to be quantified and accordingly, give the probability distribution of possible impacts. The Stochastic Analysis Modeling and Simulation Software [7] was used to generate the inflow time series at the Nile system key inflow nodes (White Nile, Blue Nile, Atbara, Rahad, and Dinder). One-hundred-inflow time series, each spanning 100 years with a 10-day time step, were generated and the GERD-HAD SIM hydrologic simulation model (WREM 2013), which was recently developed for the Ministry of Water Resources and Irrigation, Egypt, to investigate the downstream impacts of GERD. The distribution of different indicators obtained from analyzing each of the 100 generated cases was investigated, and relevant statistics derived. It is crucial to specify the main indicators that are used to address the impact on the HAD through the results. The following indicators are considered:

- Average annual level of HAD (m);
- Average annual water inflow at HAD (bcm);
- Average annual evaporation of HAD (bcm);
- Average annual energy production (HAD+OAD) (GWH/year);

- Number of shutdown years of HAD (years);
- Total water deficit DSHAD (bcm);
- Number of water deficit DSHAD;
- GERD filling period duration (years);
- Average annual evaporation of GERD (bcm); and
- Average annual energy production of GERD (GWH/year).

These indicators have been represented by using boxplots and frequency curves to get a clear summary of the results of different scenarios. The construction of the GERD can potentially usher in a new hydrologic era for the Eastern Nile region; an era without the most prominent Nile feature – annual flood. Under the current hydrologic conditions without the GERD (baseline scenario), the existing projects follow their standard operating rules developed based on historical, seasonally varying flow patterns. Namely, the regulation of Roseires, Sennar, and Merowe follows seasonal elevation target sequences, repeating year after year.

The anticipated Ethiopian policy for operating GERD is to regulate the GERD strictly based on Ethiopian (hydropower) interests without regard for downstream conditions and needs. GERD is expected to attenuate the historical seasonal flow pattern and make it more or less uniform. Under such a scenario, the target elevations of the smaller projects (i.e., Roseires, Sennar, and Merowe) do not need to follow the historical fluctuation patterns (aiming to flush the sediment and store water for irrigation during flood recession) but can maintain consistently higher water levels which will increase the evaporation losses all over the system. The results showed that GERD increases the evaporation losses in the system with about 1.42 bcm in comparison to base case scenario and 0.65 bcm in comparison to the current scenario, which shows that the Ethiopian dams have a negative impact on water availability in the system of Nile River.

Three filling rules were investigated in this study. The first one presents the Ethiopian proposed filling rule which is based on a fixed filling period length (6 years). The second rule links the filling with the annual river yield that allows the filling if the Nile yield above 85 bcm. The third rule links the filling with the annual river yield as well as to the HAD concurrent conditions, where a restriction on filling is applied if HAD levels dropped below a certain level. The results of the simulations which are summarized in Figs. 2, 3, 4, 5, and 6 showed that the GERD scenario has a drastically negative impact on HAD; the average annual water inflow to HAD would be reduced by about 5.1 bcm compared to the base case scenario to reach 63.9 bcm. GERD would reduce HAD and OAD power production by 34% compared to the base case, and the number of shutdown years of HAD would increase to 36 years compared to zero in the base case. The total water deficit in 100 years would increase to 60 bcm compared to zero in the base case. The power production of GERD seems to be attractive, but actually, the announced power generation (15,000 GWH/year) is exaggerated because GERD cannot generate 15,000 GWH except 7% of time with the Ethiopian Electric Power Corporation (EEPCO) power maximization rules. Firm energy of the GERD is about 12,300 GWH/year, which means that the effective installed capacity of turbines

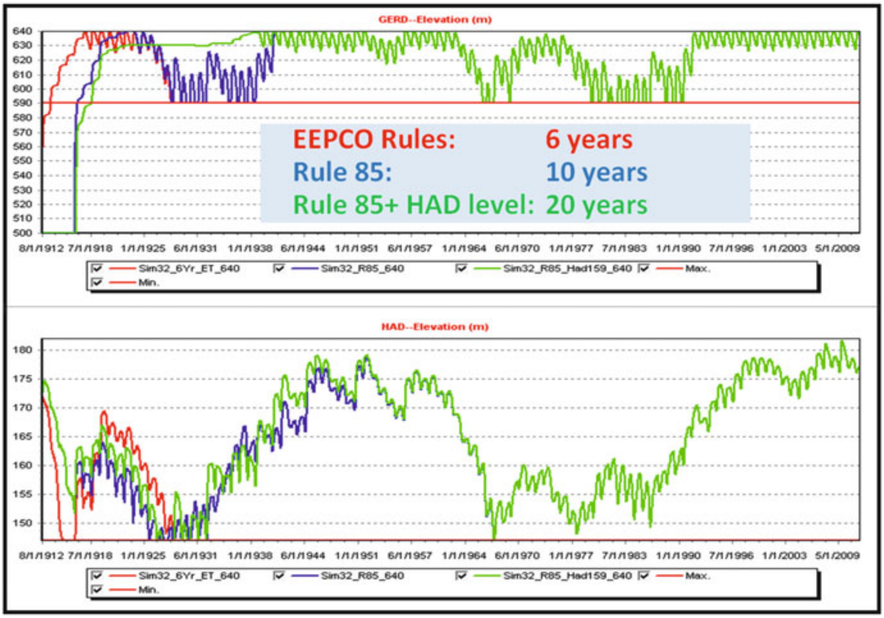

Fig. 2 Levels of GERD and HAD with different filling rules (source: [6])

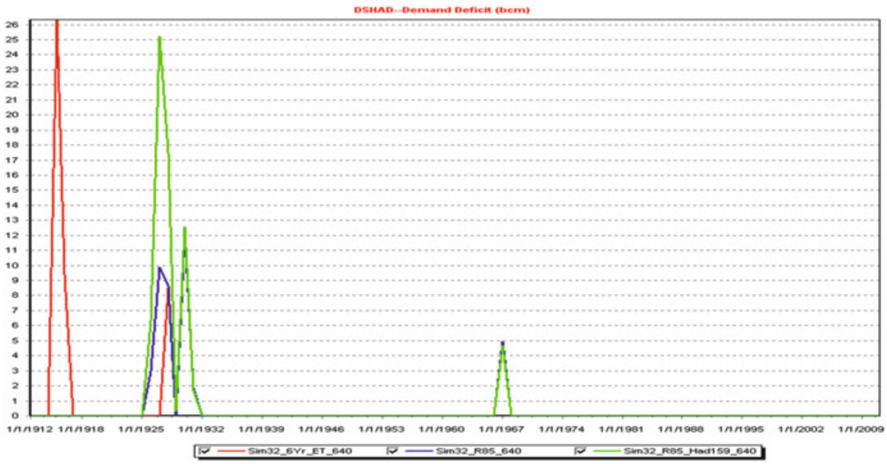

Fig. 3 Deficit of HAD with different filling rules (source: [6])

of GERD is 1,400 MW compared to the actual installed capacity of 6,000 MW. The efficiency of power generation is thus only 23% (low efficiency for power production).

The study also investigated the effect of the smaller Border dam with 14.5 bcm capacity. As can be seen from Fig. 7, the smaller dam can generate approximately

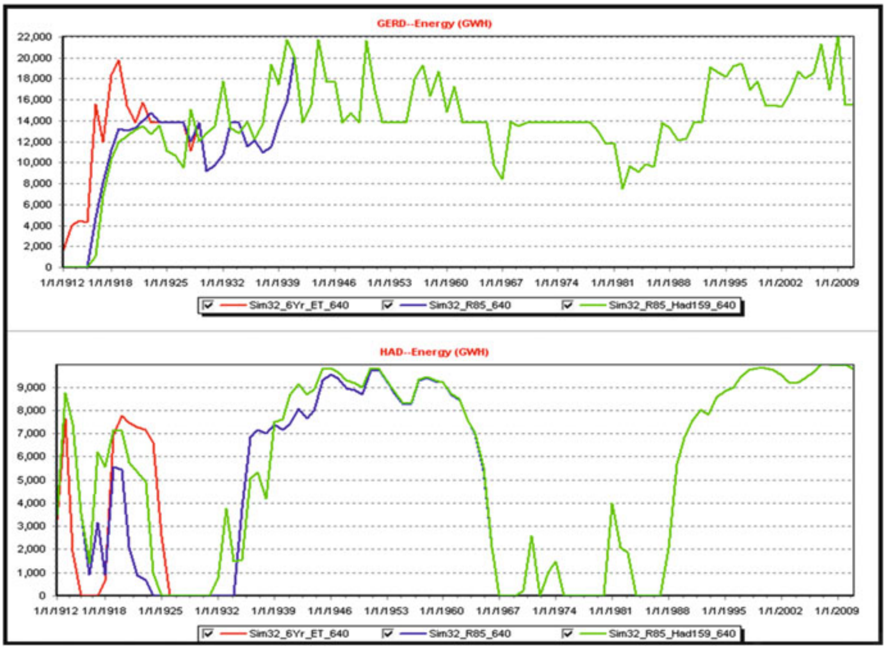

Fig. 4 Power energy of HAD and GERD with different filling rules (source: [6])

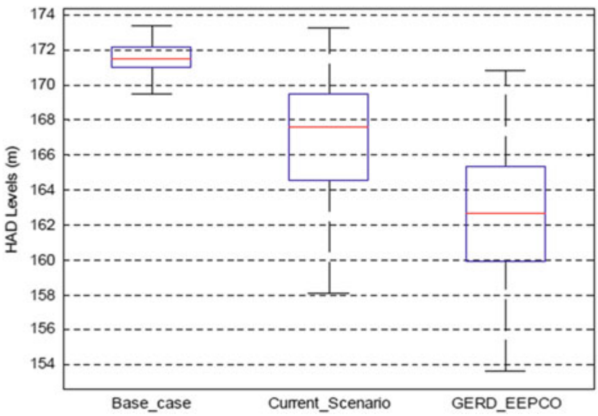

Fig. 5 Average HAD Level with different scenarios (source: [6])

70% of energy generated by GERD (about 5 times the storage capacity of Border dam), which indicates that the size of GERD reservoir is not optimized, especially that downstream adverse impacts and their associated economic, social, and environmental costs have not been taken into account.

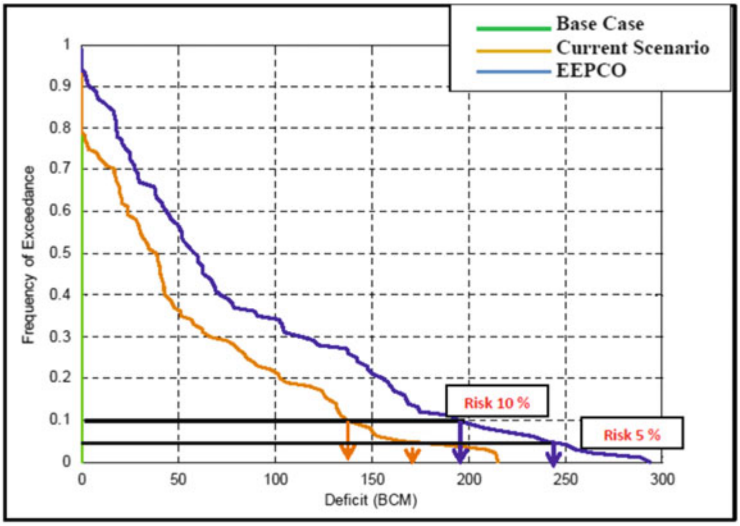

Fig. 6 Frequency curves for total water deficit DSHAD with different scenarios (source: [6])

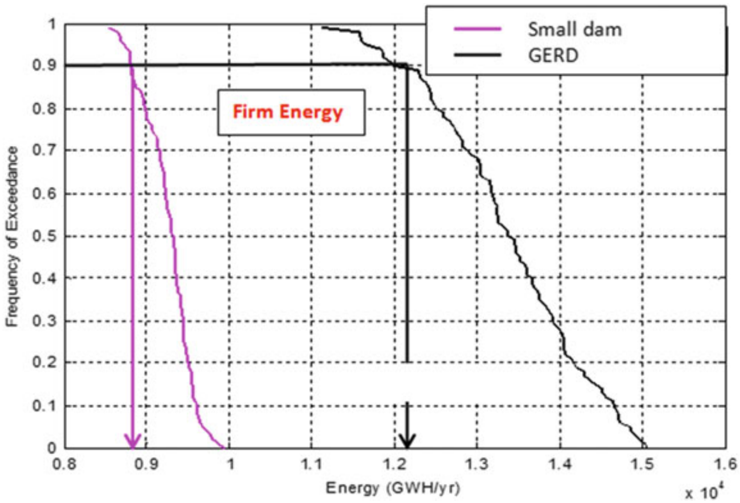

Fig. 7 Frequency curves average of annual energy production at GERD dam with different scenarios (source: [6])

In Summary, the study proposes two alternative filling rules; the 85 rule that halts GERD filling if the river yield falls below 85 bcm; with a modification to halt filling if HAD levels fall below 159 m. The average number of filling years increased from 6 years in EEPCO rule (Ethiopia Electrical Power Rule) to 11 and 14 years with the new proposed filling rules (rule 85 and rule 85 with linking to HAD level) which may affect the economic value of the GERD project if the risk to the downstream is to be reduced. The proposed filling rules do not dramatically affect the production of GERD energy (195 GWH/year reduction, 1.5%). However, these two rules decreased the total water deficit of HAD by 9 bcm (15%) and increased the energy production of (HAD+OAD) with about 400 GWH/year (5%) compared to EEPCO rule. In addition, it reduced the number of shutdown years of HAD by approximately 11%. The study concluded that GERD drastically alters the historical Nile flow regime enabling Ethiopia to exercise a high degree of flow regulation across the Blue and Main Nile reaches and that the large capacity of GERD reduces the ability of the High Aswan Dam as a long-term storage reservoir as indicated by the increase in water deficit quantity and frequency. GERD regulates the Blue Nile flow, which enables Sudanese dams to maintain consistently higher water levels. Operating these reservoirs at higher levels increases evaporation losses of the system of Nile River in addition to evaporation losses in GERD. The new proposed filling rules reduce the negative impacts of GERD, but even under these rules the impact on HAD is still unacceptable. The storage capacity of the GERD in light of the negative impacts, which are not reflected in the same magnitude as in increasing the power generation for Ethiopia, should be smaller in size for efficiency and cost-effectiveness.

4.1.3 GERD Dam Failure

One of the major impacts on the downstream countries which attracted a lot of debate is the impact of GERD failure. Among other factors that necessitate the analysis of the dam break is the current condition downstream of the dam site. Dam failures lead to catastrophic and tragic consequences in the downstream region due to the large amount of outflow associated with dam failure. In the last two centuries, floods resulting from dam failures produced some of the most devastating disasters in the world.

In this study, a full detailed analysis of the impact of GERD failure was conducted. In the first part of the study a model was developed to estimate the required breach parameters information using different numerical and empirical methods. Also the impacts of the outflow hydrograph due to dam failure on the downstream region have been presented in the form of wave celerity. Afterword, the effect of the failure of the Grand Ethiopian Renaissance Dam (GERD) on the downstream region up to High Aswan Dam (HAD) is considered.

The impacts of GERD failure on the downstream were investigated using one-dimensional and then enhanced with two-dimensional analysis models. The analysis includes assessing the risk associated with the downstream region up to the entrance of Lake Nasser due to GERD failure. The Hydrologic Engineering Center River Analysis System (HEC-RAS) developed by the US Army Corps of Engineers is used as a one-dimensional model. The International River Interface Cooperative (IRIC) developed by a cooperation between US Geological Survey (USGS), the universities of Hokkaido and Kyoto, Mizuho Corporation, and the Foundation of the River Disaster Prevention Research Institute in Sapporo, Japan is used as a

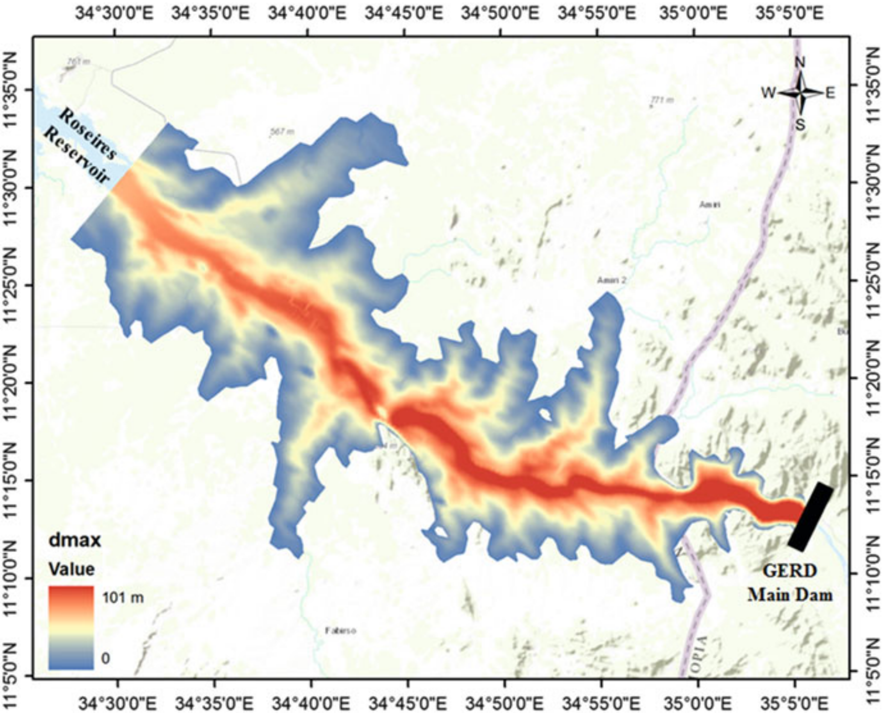

Fig. 8 Spatial distribution of max water depth along reach 1 using 2-D (Main dam) (source: [8])

two-dimensional model. Due to the large size of the modeling, the two-dimensional model is divided into 6 reaches as shown in Table 2.

Figures 8, 9, and 10 show examples of the simulation results. The results reveal that there will be catastrophic effects on Sudan especially Roseires, Sennar, and Merowe dams in addition to Al Khartoum city. Also, the study shows that the High Aswan Dam will be at risk due to GERD failure. The main findings of this study can be summarized as follows:

- The flooding extent between GERD and Roseires dam varied between 14 and 30 km according to the simulated scenario,
- The simulated scenarios (failure of GERD main dam, and saddle dam) prove that Roseires and Sennar dams will be washed out after the failure of GERD dam given that the two dams are full at GERD failure,
- If Sennar dam reservoir is empty (water level is less than or equal to 407 m), it will fail in all scenarios as its reservoir volume represents about one to seven percent of the released volumes,
- The flooding extent between Roseires and Sennar dams varied between 71 and 126 km according to the simulated scenario,
- In case of GERD main or saddle dam failure, Al Khartoum city will suffer severe conditions as the water depth above natural ground level will be about seven to eleven meters,

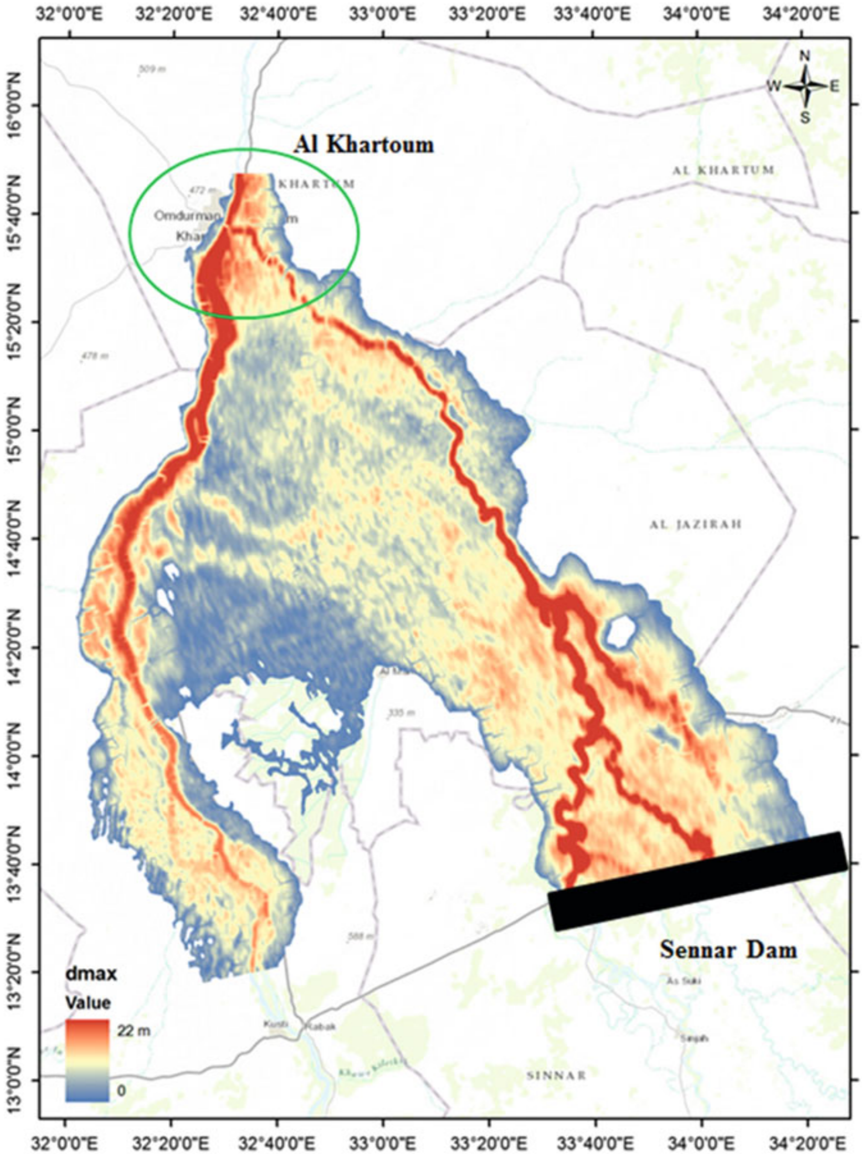

Fig. 9 Spatial distribution of max water depth along reach 3 using 2-D (Main dam) (source: [8])

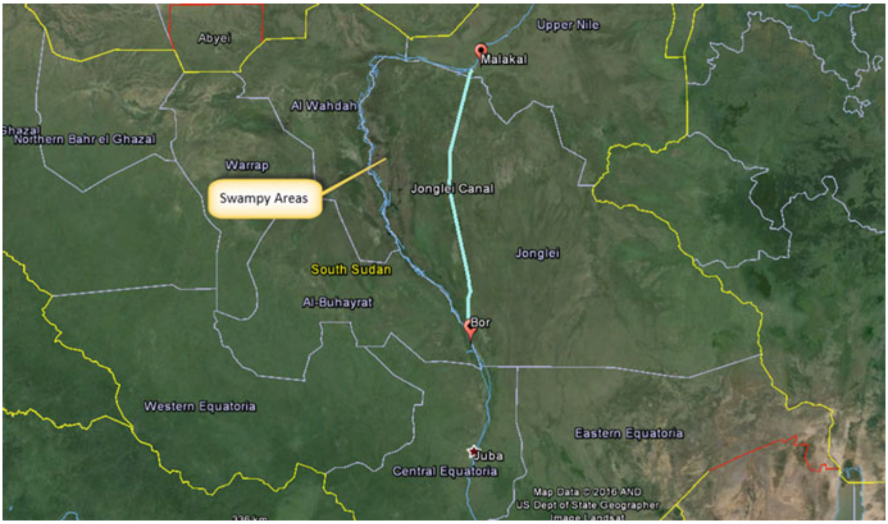

Fig. 10 Jonglei Canal location with reference to the Sudd swamps (source: [9])

- Gabal Al Awlia dam which is located on the White Nile to the upstream of Al Khartoum city will be affected significantly in both first and second scenarios. This effect may cause the failure of this dam,
- The flooding extent between Sennar dam and Al Khartoum city varied between 54 and 176 km according to the simulated scenario,
- The flooding extent between Al Khartoum city and Merowe dam varied between 36 and 40 km according to the simulated scenario,
- Merowe dam will be washed out due to failure of GERD as it will be overtopped in all cases,
- The peak inflows to Lake Nasser in case of main or saddle dam failure are comparable,
- The flooding extent between Merowe dam and Lake Nasser varied between 23 and 27 km according to the simulated scenario,
- Along the simulated reaches there are no water escapes through which flood water will be taken far away from the main river route,
- About sixty percent of the total volume of GERD, Roseires, Sennar, and Merowe dams will arrive at the entrance of Lake Nasser in both scenarios of GERD failure.

4.2 *Detailed Analysis of an Irrigation Mega Project (Case of Irrigation Projects in the Eastern Nile Basin)*

As mentioned previously, constructing large dam on the Blue Nile has drastic impacts on Egypt. It goes without saying that adding the proposed agricultural development will increase the negative impacts in Egypt and may cause irreversible damage to the ecosystem. To illustrate the impacts of irrigation mega projects in Eastern Nile on Egypt, two scenarios were set to address the impacts on HAD. The first scenario is the base case whereas; in the second scenario examines different irrigation projects. It should be mentioned here that the irrigation scenario did not consider the construction of the proposed dams in order to illustrate the separate impact of irrigation projects. It is worth mentioning that the impact of the hydropower dams presented in the above section and the irrigation development scenario in this section will be accumulated (the impact of each scenario projects will be added to the subsequent scenario).

Table 4 describes the distribution of proposed irrigation schemes on the two investigated scenarios. As depicted from Table 4, the base case scenario describes the current situation. It contains the main development projects in both Ethiopia and Sudan. It will contain: TK5 on Atbara River and Tana Beles hydropower plant in Ethiopia; Roseires and Sennar on the Blue Nile, Girba on Atbara, and Merowe on Main Nile in Sudan. The total annual abstracted water from the system is estimated at 16 bcm. Scenario 1 will encompass the projects according to a timeframe; the next ten years where Ethiopia will be able to develop 130,000 ha with annual water requirements of 1.23 bcm. In Sudan, 210,000 ha with annual water requirements of 2.30 bcm and Roseires dam heightening will be considered.

To assess the impacts of the irrigation projects, the Nile Decision Support Tool (NILE-DST) was used. The Nile-DST has been developed as part of the Nile Basin Water Resources Project in collaboration with the Nile countries. The model's purpose is to assess the benefits and tradeoffs associated with various basin-wide water development and management options. To avoid dependence on the historical pattern, which is unlikely to be repeated in the same order, a stochastic approach was used to assess the impact of the development scenarios on the HAD. The full historical series (1913–2002) was used to generate different

Table 4 Reach lengths of 2-D simulation

Reach no.	From	To	Length (km)
1	GERD	Roseires dam	123
2	Roseires dam	Sennar dam	297
3	Sennar dam	Al Khartoum city	389
4	Al Khartoum city	Contraction area	97
5	Contraction area	Merowe dam	676
6	Merowe dam	Lake Nasser	1,088
		Total length	2,670

synthetic series by random sampling using blocks of sufficient length to preserve the correlation structure of the series. A total of one hundred realizations were used in the analysis. To assess the impacts the following indicators were used:

- Number of deficit months: (number of months having shortage of downstream requirements);
- Number of deficit years (number of years having shortage of downstream requirements);
- Total deficit (total amount of shortage of downstream requirements in 90 years);
- Average Annual level (average level of Lake Nasser);
- Average annual energy (average energy of HAD hydropower station).

Table 5 summarizes the results of the simulations.

As depicted from Table 3, scenario 1, which includes developing of 340,000 ha and commissioning of Roseires dam heightening will reduce the average annual inflow at HAD by 4.1 bcm which will result in lowering the average annual HAD level from 170.0 (Base Scenario) to 164.0 m, and reducing the average annual power production from 10,999 GWh (Base Scenario) to 9,757 GWh. Shortage in water requirements will be experienced, where, within the 90 years simulation period, the average total deficit will increase from 18.54 (Base Scenario) to be 65.4 bcm, which occurs in 8 years spread over 35 months.

4.3 Detailed Analysis of Canalization and Streaming (Jonglei Canal)

The critical water stress in Nile countries has drawn attention to the huge losses that occurs at swampy areas in the Nile Basin. Several projects were proposed to tap these losses. One of these projects is Jonglei Canal in the Sudd swamps in Southern Sudan. Jonglei Canal is one of the projects that was proposed by Egypt and Sudan to capture the huge water losses in the Sudd region. It connects Bahr el Jebel directly from Bor city to Hillet Doleib city (close to Malakal downstream the Sudd region) as shown in Fig. 10.

The estimated losses in the Sudd swamp are in the order of 20 bcm/year on average. Construction work on Jonglei Canal began in 1978 but it stopped due to the political instability in Sudan. The work stopped at year 1984 after excavating about 240 km of the canal out of 360 km (total length).

The canal has been under debate. Some people see it as an economic, socially, and culture-wise boost as well as a water savings. Others have environmental concerns that the size of the swampy area will be reduced, which will adversely affect the grazing activities of the local tribes living in the area.

The upstream countries in the Equatorial Plateau announced that they have several plans to utilize the Nile River flow for several development projects which add another question on the effect of Jonglei Canal under the potential

Table 5 Description of the development scenarios (source: [10])

	Hydropower				Irrigation			
	Ethiopia		Sudan		Ethiopia		Sudan	
	Project	Capacity (bcm)	Project	Capacity (bcm)	Project	Area (ha)	Project	Area (ha)
Base-case (current situation)	TK5 Tana Beles	9.2	Merowe Roseires Sennar Girba	12.4 2.0 0.6 0.5	–	–	Gezira, Managil, Rahad, Sennar Pumps, Halfa	15.5
Scenario 1	–	–	Roseires Ht.	6.0	Upper Beles Tana Humera	50,000 50,000 30,000	Rahad Kenana I Merowe	43,000 42,000 125,000

development projects. Accordingly, this study adopts a comprehensive approach to evaluate all the possible impacts related to the project as well as to evaluate the hydrological feasibility of the project under the new development plans of the Equatorial countries.

The study presents the plans of the Equatorial lakes countries for utilization of the Nile River flow. If these projects are implemented, the flow of the Equatorial lakes to Bahr el-Jebel in Southern Sudan will be reduced. Accordingly the flow in the Sudd region will decrease and hence a decrease in the losses in the region can be expected which will decrease benefits expected from Jonglei Canal. The study evaluates the impact of these projects, if implemented, on the technical feasibility of Jonglei Canal in the Sudd region in the Southern of Sudan.

The data of development projects of the Equatorial lakes countries for utilization of the Nile River flow were extracted from the documentation of the Nile Basin Initiative and the National plans of the Upper Nile countries. It was found that agricultural development projects are suggested by several Equatorial Plateau countries, namely Uganda, Kenya, Tanzania, Ruanda, and Burundi. Figure 11 shows the location of the development projects in the Equatorial upstream countries highlighted in green. As shown in the map, all the projects are located in the area surrounding Victoria Lake and its tributaries. Accordingly the water requirements for these projects will be abstracted from Victoria Lake. The estimated water requirements for the different agricultural development projects are summarized in Tables 6 and 7.

The baseline scenario for the existing state of upstream development may be represented with unregulated equatorial lakes, and no sizeable reservoirs along the Blue Nile until now. Existing reservoirs include the Owen Falls Dam in Uganda, Gebel el Aulia, Sennar, Roseires, Khasm el Girba in Sudan, and the Old Aswan and High Aswan Dams in Egypt.

Three alternate upstream development scenarios were considered in this study. All scenarios assume full regulation of the Equatorial lakes and hydropower facilities along the Victoria and Kyoga Nile reaches. Scenario A assumes that all the

Fig. 11 A map showing the upstream countries development projects ([11])

Table 6 Summary of the impacts of irrigation projects on HAD (source: [10])

	No. months		No. years		Total deficit (bcm)		Average HAD levels (m)		Average HAD energy (GWh)	
	Base	Scen. 1	Base	Scen. 1	Base	Scen. 1	Base	Scen. 1	Base	Scen. 1
Mean	10.1	34.92	2.37 (3.0)	7.66	18.5	65.38	170	164	10,998	9,757
Std. error of	1.77	3.67	0.39	0.74	3.23	7.23	0.3	0.4	61	77
Median	0	30	1	7	5	55	171	164.5	11,100	9,700
Std. deviation	14.3	29.57	3.12	6	26	58.32	2.4	3	496	623
Minimum	0	0	0	0	0	0	164	157.5	9,700	8,300
Maximum	60	125	12	24	110	235	175	172	11,900	11,400
Percentiles 25%	0	12.5	0	3	0	17.5	168	162	10,650	9,300
50%	0	30	1	7	5	55	171	164.5	11,100	9,700
75%	20	52.5	4	11	35	100	172	166	11,400	10,200

Table 7 The Development projects proposed by the Upper Nile countries (source: [9])

Country	Project	Development projects	Water req. (bcm/year)
Uganda	Hydropower	Bugagali and Karuma dams	
	Agricultural	440 thousands feddans	1.6
Kenya	Hydropower		
	Agricultural	625 thousands feddans	1.9
Tanzania	Hydropower		
	Agricultural	824 thousands feddans	2.65
Ruanda and Burundi	Hydropower	Rusomo dam	
	Agricultural	35 thousands feddans	0.1

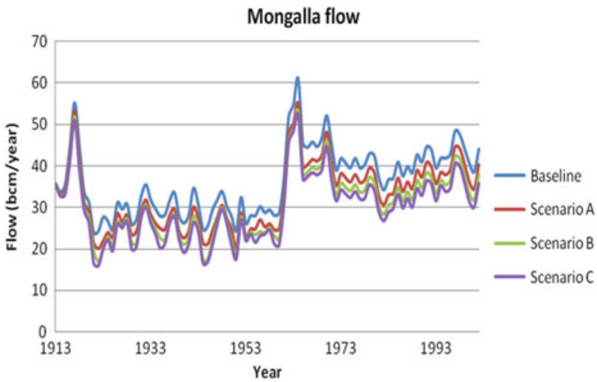

Fig. 12 Simulated flow at Mongalla for the different development scenarios (source: [9])

agricultural development projects are completely implemented with a total annual water requirement of 6.25 bcm abstracted from Lake Victoria as shown in Table 7. Scenario B assumes that all planned development projects increased by 50%. The annual abstraction from Lake Victoria is assumed 10 bcm. Scenario C assumes an increase in the annual total water requirements of the development projects by 100%. The annual abstraction from Lake Victoria is assumed 13 bcm.

The Nile DST model was applied in this study to determine the deficit in Nile River flow at Mongalla (upstream Jonglei Canal) and at the High Aswan Dam (HAD) as a result of the upstream development projects. Figure 12 shows the simulated flow at Mongalla which clearly indicates a significant decrease in the flow for the different scenarios especially in the dry seasons. Summary of the simulated results are summarized in Table 7.

To assess the feasibility of Jonglei Canal under the new development projects, the losses through the Sudd swamps corresponding to the simulated annual Mongalla flow time series obtained from the Nile DST model were calculated. The losses through the Sudd swampy area were then compared to the planned water savings for Jonglei Canal. If the losses exceeded or equaled the planned water saving for Jonglei Canal that means that the canal will still be reliable with respect to the planned water savings after the implementation of the upstream countries development projects. If the losses were less than the planned water savings, then

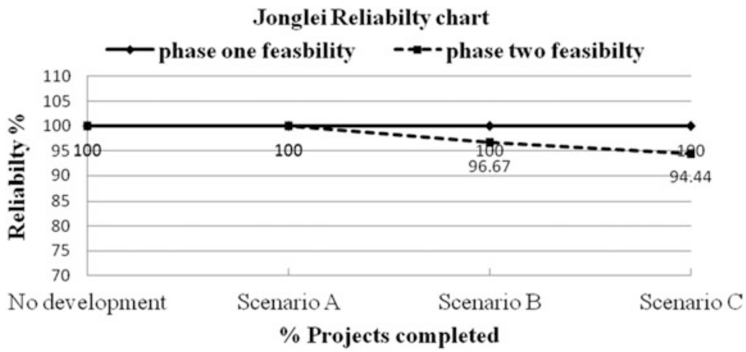

Fig. 13 Reliability of Jonglei Canal with its two phases for the different scenarios (source: [9])

that means a failure occurs in that year and Jonglei Canal will not be reliable in achieving its water savings. The technical feasibility of the Jonglei Canal project may be described by the canal reliability to guarantee the planned annual water savings which are 4.8 bcm for the first phase and 7 bcm for the second phase. The reliability is computed as the percentage of the years of success to achieve the required target of saving. It should be mentioned that in this case the total priority is given to Jonglei Canal with respect to the flow and not considering any negative impacts on the Sudd area swamps including the large reductions occurring in some years.

Figure 13 shows the reliability of Jonglei Canal with its two phases for the different scenarios. For the first phase of the canal (4.8 bcm annual saving), Jonglei Canal was found to be perfectly reliable in covering the planned water savings for all the development scenarios. However, for the second phase the reliability of Jonglei Canal decreased for the development scenarios B and C to be 96.67% and 94.44%, respectively. A reliability of 94.44% means that in a hundred years four failures will occur in which Jonglei Canal will not be able to cover the planned water saving.

To assess the environmental impacts on the swampy areas due to the construction of Jonglei Canal, HEC-RAS model is used to simulate the resulting flow from the Nile DST model through Jonglei Canal and Bahr el Jebel. The model is also used to assess the existing Jonglei Canal cross-sections and evaluate the effect of both Jonglei Canal and the development projects on the swamps.

Two steady HEC-RAS models are developed for the study area; one model for Bahr El Jebel River and the swamps and the other model is for Bahr el Jebel after the construction of Jonglei Canal. The models were developed using the cross-sectional data available for Bahr El Jebel River and Jonglei Canal. Several scenarios of study were developed including a baseline scenario, Jonglei Canal with and without control structures, and implementation of the upstream developments with and without Jonglei Canal and vice versa.

The Uncontrolled flow through Jonglei Canal was calculated. Table 8 shows the average flows entering Jonglei Canal for the different development scenarios A, B, and C at two phases. An uncontrolled canal may be adequate for the first phase of

Table 8 Summary of the simulated results at Mongalla (source: [9])

	Min flow (bcm/year)	Max flow (bcm/year)	Avg flow (bcm/year)	Max diff (bcm/year)	Avg deficit (bcm/year)
Baseline	23.98	61.01	36.39	0	0
Scenario A	20.06	54.94	32.81	6.07	3.60
Scenario B	17.00	53.34	30.97	7.97	5.40
Scenario C	15.92	52.22	29.67	9.28	6.70

Table 9 Uncontrolled flow of Jonglei Canal under the different development scenarios (source: [9])

	Average flow (bcm/year)	Minimum flow (bcm/year)
Scenario A	5.14	4.34
Scenario B	5.00	4.18
Scenario C	4.96	4.05

the Jonglei project, where the planned annual water saving is 4.8 bcm. However, control structures must be introduced in the second phase, without which the average annual flow will be around 5 bcm^3 which is 2 bcm^3 less than the planned water saving for this phase.

The percentage reduction in swamp area due to the operation of Jonglei Canal to divert a part of the Bahr el Jebel flow in the cases of the uncontrolled and controlled flow (the two phases) are summarized in Table 9. The values are shown for different inflow values. These values are very wet (largest value of annual historical flow), average wet (75th percentile value of historical flow), average flow, average dry flow value (25th percentile value of historical flow), and the lowest flow through the historical flow data. Table 9 shows that the area reduction in the swamps for the average wet and average flows are the same. It also shows that Jonglei Canal without the upstream development will cause reduction on the order of only 5–10% in the swampy area.

The combined impacts of Jonglei Canal and the upstream development projects on the size of the swampy area are also assessed. The results are presented in Tables 10, 11, 12, and 13 for the three development scenarios, respectively. It is evidenced from the three tables that the average reduction in the swampy area will increase after the implementation of the upstream development projects. The average range of the reduction will be from 7.6% to 13.8%. Under development scenario A, the reduction in the swampy area is found to range within 7–16% in the most severe case. The reduction in the swampy area will increase to 9–19% under development scenario B. The results of scenario C are not very different from scenario B.

In conclusion, the upstream Nile river development projects in the equatorial Lakes will cause a reduction in the Nile River average flow reaching Mongalla in the order of 10–20%. This reduction will be transferred at Aswan in order of 1.5–2.5%. The first phase of Jonglei Canal will increase annual average flow at

Table 10 Percentage reduction in the Sudd region swamps area due to operation of Jonglei Canal without considering upstream developments (source: [9])

Scenario	Very wet	Average wet	Average	Average dry	Very dry
Uncontrolled	4.37	5.74	5.3	5.78	6.6
Phase One	1.96	4.7	4.7	5.51	6.75
Phase Two	4.8	6.8	6.83	9	9.61

Table 11 Percentage reduction in the Sudd region swamps area due to combine effect of operation of Jonglei Canal and considering development scenario A (source: [9])

Scenario	Very wet	Average wet	Average	Average dry	Very dry
Uncontrolled	7.2	8.54	7.64	11.41	11.59
Phase One	6.37	8	7.32	11.48	12.11
Phase Two	7.62	8.24	9.41	13.76	16.07

Table 12 Percentage reduction in the Sudd region swamps area due to combine effect of operation of Jonglei Canal and considering development scenario B (source: [9])

Scenario	Very wet	Average wet	Average	Average dry	Very dry
Uncontrolled	7.82	10.75	9.45	12.52	16.57
Phase One	7.44	10.1	9.1	12.67	18.05
Phase Two	8.24	12.37	12	15.33	24.45

Table 13 Percentage reduction in the Sudd region swamps area due to combine effect of operation of Jonglei Canal and considering development scenario A (source: [9])

Scenario	Very wet	Average wet	Average	Average dry	Very dry
Uncontrolled	8.19	12.1	11.1	12.94	19.44
Phase One	7.81	11.67	10.81	13.76	21.28
Phase Two	8.6	13.56	13.83	16	29.03

Aswan with about 3%, and this increase will go down to 1–2% if the upstream development project takes place. If Jonglei Canal is implemented with its two planned phases, the Nile River annual average flow at Aswan will increase with about 4%, but it will be only 2.5–3% if the upstream development projects are implemented. The reduction in the swampy areas due to the upstream development projects ranges from 2% to 6%. This reduction will increase up to 10%, on average years, if Jonglei Canal is fully implemented.

5 Conclusions

This study presented an overview of the impacts of the Upper Nile mega projects on the water resources of Egypt. Examining the mega development project within the Nile River Basin reveals an obvious conflict interest between the needs of upstream and downstream countries. The sensitive condition of water resources in Egypt reduces its ability to cope with any reduction in Nile flow. The available water resources for use in Egypt are 55.5 bcm/year, and 1.3 bcm/year effective rainfalls, non-renewable groundwater for western desert and Sinai, while water requirements for different sectors are in the order of 80.0 bcm/year. The gap between the demand and supply is about 20 bcm/year (33% from renewable water resources). This gap is covered by recycling which makes the overall efficiency of the Nile system in Egypt is more than 80%, but at the expense of water quality. In addition, the food gap increases in Egypt (e.g., food gap reached 6,000 million US$ in 2013 against 2,905 million US$ in 2004) makes the sensitivity to any reduction in water is even more sever.

The possible impacts of different development projects as depicted from all these studies may be summarized as follows:

- The large capacity of GERD reduce the ability of the High Aswan Dam as a long-term storage reservoir as indicated by the increase in water deficit quantity and frequency.
- The filling of GERD will have very significant negative impacts on the Egyptian water and energy sectors depending on the adopted reservoir filling rule and GERD dam size.
- The proposed agricultural development projects in both Ethiopia and Sudan have an adverse impact on Egypt. Accordingly, the water requirements for irrigation projects must be secured before implementation of such projects.
- The entire system of the Nile River should be studied to examine whether all these ambitious proposed agricultural and hydropower projects can be established together.
- The needs for development in the entire basin and water scarcity conditions highlighted the vast amount of water losses occurring in the swampy areas of the Nile River basin. Saving these water losses becomes a real hope to reduce the food gap and promote development in all Nile Basin countries.

Therefore, the apprehension that Egypt has from the negative impacts of unilateral development in upstream countries is fully justified. The interests of upstream and downstream countries are not clear-cut because of the economic interaction. However, following and respecting the general international rules of win-win, no harm, and no regret is the only way for regional development for the interest of all basin people.

References

1. Shahin M (1985) Hydrology of the Nile basin. Elsevier, The Netherlands
2. Sutcliffe J, Parks Y (1999) The hydrology of the Nile. IAHS Press, Wallingford
3. MoWR (Ministry of Water Resources) Ethiopia (2009) Mandaya and Beko Abo Dams Feasibility Studies Terms of Reference
4. World Bank: Africa Development Indicators (2006) The International Bank for Reconstruction and Development, World Bank, Washington, DC
5. Nile DST (2007) (Nile Decision Support Tool)
6. Senosy M (2015) Stochastic analysis of the impact of the grand Ethiopian renaissance dam on high Aswan dam (HAD). M.Sc. Thesis, Cairo University
7. SAMS (Stochastic Analysis, Modeling, and Simulation) (2007) SUBR, University of Colorado
8. Soliman A (2015) Hydrological impact of renaissance dam failure on the downstream up to the high Aswan dam. Ph.D. Thesis, Cairo University
9. Allam M (2008) Hydrologic and hydraulic study of Jonglei canal under the potential development schemes in the upper Nile countries. M.Sc. Thesis, Cairo University
10. Gharib A (2011) Impacts of anticipated development in the Eastern Nile plateau on the water resources of Egypt. Ph.D. Thesis, Cairo University
11. NBI (2012) State of the River Nile Basin. Nile Basin Initiative

Part V
Climate Change: Variability, Vulnerability and Adaptation

Nile Basin Climate Changes Impacts and Variabilities

Khaled Khir-Eldien and Sherien Ahmed Zahran

Abstract Global climate is changing and this is apparent across the Nile basin countries in a wide range of observations. The global warming of the past 50 years is primarily due to human activities, climate change is already affecting the Nile basin people in far-reaching ways. Certain types of extreme weather events with links to climate change have become more frequent and/or intense, including prolonged periods of heat, heavy downpours, and, in some regions, floods and droughts. In addition, warming is causing sea level to rise and oceans are becoming more acidic as they absorb carbon dioxide. These and other aspects of climate change are disrupting people's lives and damaging some sectors of our economy. So this chapter presents the climate changes and variability all over the basin and sub-basins. It structures around historical climatology and hydrology of Nile basin, variability of Nile climate, in addition to the Impacts of Climate Change on Growth and Development.

Keywords Climate impacts, Climate variability, Nile basin climatology, Nile basin hydrology

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K. Khir-Eldien (✉)
Environment and Climate Research Institute (ECRI), National Water Research Center (NWRC), Cairo, Egypt
e-mail: kzurich22@gmail.com

S.A. Zahran
Climate and Environment Risk Assessments Laboratory (CERAL), Environment and Climate Research Institute (ECRI), National Water Research Center (NWRC), Cairo, Egypt
e-mail: shereinzahran@gmail.com

A.M. Negm (ed.), *The Nile River*,
Hdb Env Chem (2017) 56: 533–566, DOI 10.1007/698_2016_116,

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Acronyms and Abbreviations

AOGCM	Atmosphere-Ocean General Circulation Model
AR4	Fourth Assessment Report of the Intergovernmental Panel on Climate Change (2007)
AR5	Fifth Assessment Report of the Intergovernmental Panel on Climate Change
CERAL	Climate and Environment Risk Assessments Laboratory
ECRI	Environment and Climate Change Research Institute
DCF	Delta change factor
ENSO	El Niño Southern oscillation
ENTRO	Eastern Nile Technical Regional Office
GCM	Global Circulation Model
GPCC	Global Precipitation Climatology Center
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Inter-Tropical Convergence Zone
IOD	Indian Ocean Dipole
IOZM	Indian Ocean Zonal Mode
NBI	Nile basin initiative
NCAR	National Center for Atmospheric Research
NFS	Nile Forecast System
NWRC	National Water Resources Center
RACMO	Regional Atmospheric Climate Model
RCM	Regional Climate Model
RCPs	Representative Concentration Pass Ways
SOI	Southern Oscillation Index
SRES	Special Report on Emissions Scenarios
SAR	Second Assessment Report
SST	Sea Surface Temperature

TAR Third Assessment Report of the Intergovernmental Panel on Climate Change (2001)

1 Background and Justifications

Climate change is a grave threat to the developing world and a major obstacle to continued poverty reduction across its many dimensions first, developing regions are at a geographic disadvantage: they are already warmer, on average, than developed regions, and they also suffer from high rainfall variability. As a result, further warming will bring poor countries high costs and few benefits. Second, developing countries – in particular the poorest – are heavily dependent on agriculture, the most climate-sensitive of all economic sectors, and suffer from inadequate health provision and low-quality public services. Third, their low incomes and vulnerabilities make adaptation to climate change particularly difficult. Because of these vulnerabilities, climate change is likely to reduce further already low incomes and increase illness and death rates in developing countries. Falling farm incomes will increase poverty and reduce the ability of households to invest in a better future, forcing them to use up meager savings just to survive. At the national level, climate change will cut revenues and raise spending needs, worsening public finances. Climate-related shocks have sparked violent conflict in the past, and conflict is a serious risk in areas such as the Nile basin.

The Nile, though the longest river in the world with its 3 million km^2 Basin area, its runoff potential is small. The basin is also prone to sever inter- and intra-annual variability of rainfall. The basin's population is expected to double every 25 years. High population growth and increased variability of rainfall is forcing many of the countries, which hitherto depend on rain fed agriculture, into irrigated farming system thus increasing overall consumptive water demand on the system.

The Nile basin drains from South to North and can be divided into 15 sub-basins as shown in Figs. 1, 2, 3, and 4. The South-North orientation of the River Nile on the African continent means that the extreme ends of its basin are subject to serious variability with respect to climate. The North, for instance, (Egypt and Sudan in particular) is characterized by extreme aridity and extensive desert while in the South and East strong rainfall results in lush vegetation, humid conditions, and even tropical rainforest in some locations.

On an average year the basin receives some 650 mm of rainfall corresponding to around 1,900 bcm of water per year. Long-term mean annual flow at Aswan is only about 84 bcm/year, making the annual runoff coefficient of the basin around 4.5% [1]. This figure is small, for example, is just 10% of that of the Rhine. This is explained by the fact that a significant portion of the basin comprises arid and hyper-arid zones that are large in surface area yet contribute only negligibly to basin runoff. Added to this, are the evaporation losses from major swamp areas which cause up to 30% of the basin's rainfall to be lost before being used for any purpose. On the Ethiopian massif, the key contributor of Nile flows, the Kiremt rains produce

Fig. 1 Nile sub-basins

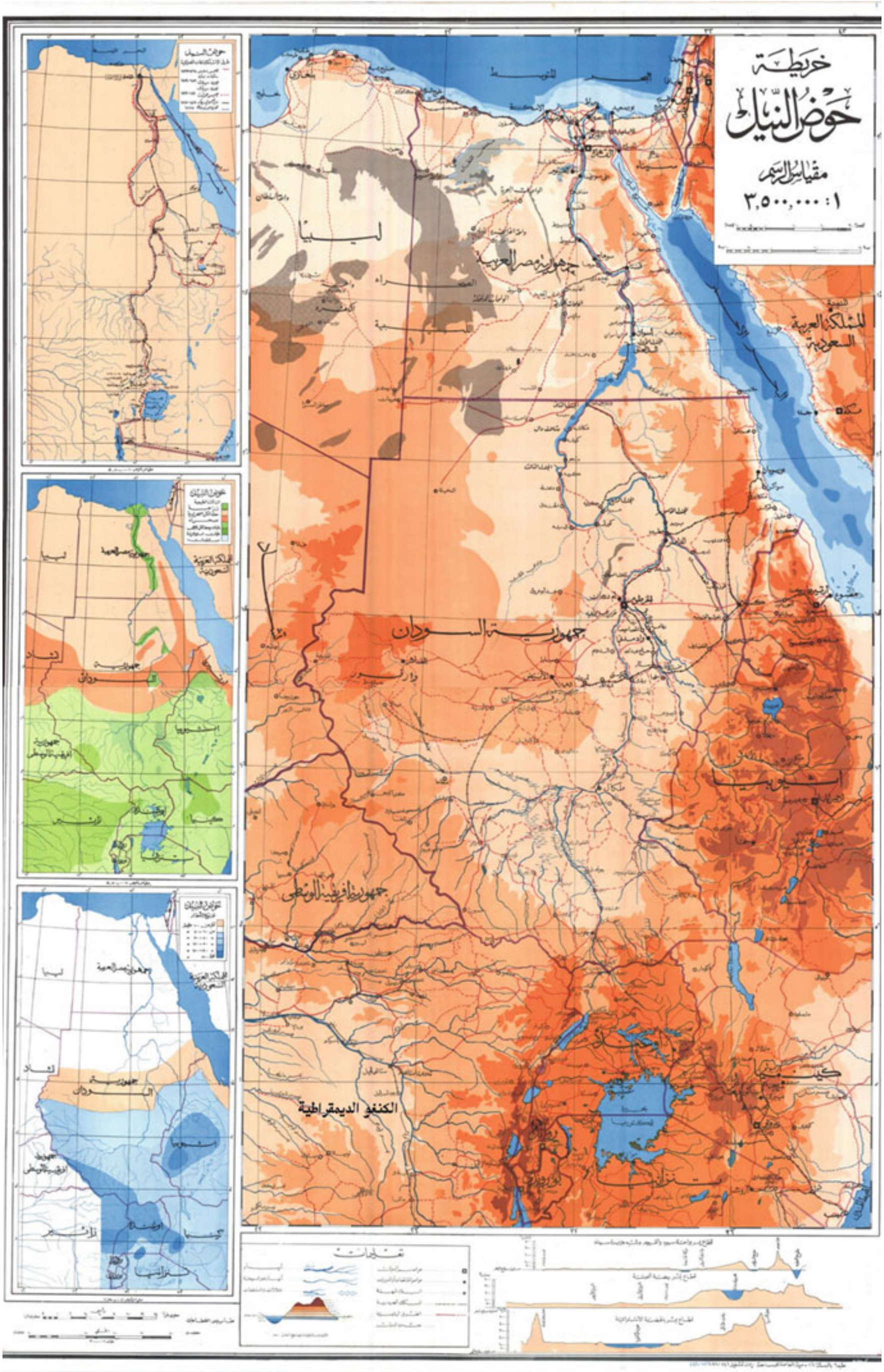

Fig. 2 Nile River, scale 1:3,500,000

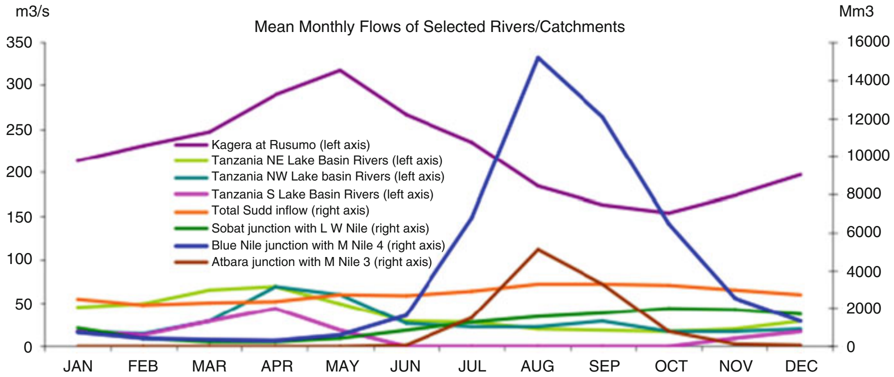

Fig. 3 Mean monthly flows of selected rivers/catchments

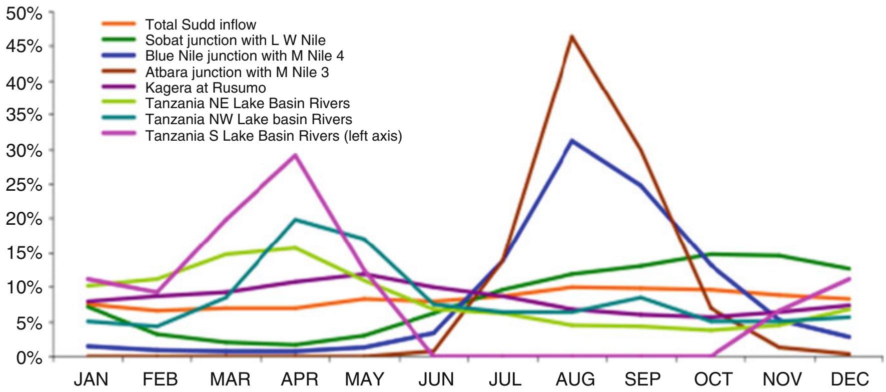

Fig. 4 Mean monthly flows of selected rivers/catchments as % of annual flows

the main June–November spate. This spectacular phenomenon is the combination of three mechanisms: the northward movement of the Inter-Tropical Convergence Zone (ITCZ) (summer monsoon) over the highlands, before retreating again, the tropical "upper easterlies," and local convergence in the Arabian Sea region. The resulting rainfall is often intense, and causes rapid runoff leading to major soil loss. In the south precipitation is also stormy and caused by convection, orthographic conditions or frontal conditions caused by the collision of dry north-east boreal winds with the moist air above the Indian Ocean being blown into the region from the South. Flows moreover are seasonal as indicated by the following figures which show also that the seasonal peaks arise earlier in the NEL sub-region than the EN.

The basin includes a wide variety of ecosystems; many of them are highly water dependent such as important wetlands in Kenya, Uganda, and Sudan. Equally, the basin contains three large lakes – namely Victoria, Albert, and Tana. Human development has already begun to compromise the sustainability of key environmental assets. Reported trans-boundary environmental issues accordingly include:

- Cross-border physical or chemical pollution arising from deforestation and soil erosion which increases vulnerability to drought; sedimentation (of wetlands, reservoirs, canals, and drains); and greater floods downstream. In addition urbanization, industrialization, and increased use and improper application of pesticides and fertilizers lead to increased runoff and pollution that harm downstream water users.
- Loss or degradation of wetlands and lakes – water dependent ecosystems throughout the Nile basin contribute to the stability, resistance, and resilience of both natural and human systems to stress and sudden changes.
- Need for trans-boundary cooperation to protect key habitats. Many key plant and animal species have habitats in adjoining countries, often requiring cross-border protected areas.
- Lack of early warning systems.
- Spread of exotic and invasive water weeds. Water hyacinth and other invasive aquatic weeds have spread throughout many parts of the Nile basin, impairing the functions of natural ecosystems, threatening fisheries, and interfering with transportation.
- Waterborne diseases such as malaria, diarrhea, and bilharzia (schistosomiasis) are among the leading causes of death especially among the old and very young. Their spread is related to a variety of different factors such as increased breeding ground for disease vectors, growing resistance to drugs that fight these diseases, and lack of sanitation infrastructure, often compounded by the lack of adequate hygiene education.

Note: Figures 1, 2, 3, and 4, which are offered as heuristic illustrations only, have been consolidated from several data sources between them covering the period 1900–1997, but with no single run of data less than 77 years.

Water use in the basin is widespread and varied and includes water supply and sanitation; agriculture (including a large livestock sector); capture and culture fisheries; hydropower generation; industry and mining; navigation and tourism. But despite the significance of the development that has already taken place, great undeveloped potential remains – and this is especially so in terms of irrigation and power generation both of which represent pressing concerns among the riparian stakeholders. Realization of the remaining potential needs, however, greater coordination and cooperation between these stakeholders. Not only is it necessary to mitigate or obviate the trans-boundary environmental challenges listed above. It is also necessary that future development pays due regard to changing climatic conditions. These conditions may probably increasing scarcity/unmanageability of water; changing demographics; new economic development opportunities; food security/poverty alleviation. Consequently, basin welfare and trans-boundary cooperation promote as alternatives to development trajectories that are based on purely local advantage.

2 Historical Climatology and Hydrology of Nile Basin

2.1 Climate of Eastern Nile

Figure 5 shows average annual rainfall and air temperature contours for the Eastern Nile River basin, based on spatial interpolation of data in the OSIs obtained from the Egyptian, Ethiopian, and Sudanese governments [2]. Especially in Ethiopia, where the National Meteorological Services Agency was established only in the 1950s, there are few long-duration rainfall series available for the instrumental period – the longest are for Addis Ababa (since 1898), Gore and Gambela (extending back to the early 1900s); for more details, see Conway et al.[3]. Temperature records are even sparser than those for precipitation; the longest series is again for Addis Ababa, dating back to 1898.

The five sub-basins of the Eastern Nile are the Baro-Akobo, White Nile, Blue Nile, Tekeze-Atbara, and Main Nile (Fig. 6). Each of these has distinct climate and physical characteristics, which are now discussed in more detail, beginning with the Blue Nile because it is the focus of the climate change study motivating this literature review, and then proceeding upstream for the remaining sub-basins in this system, from south to north (Baro-Akobo, White Nile, Tekeze-Atbara, and Main Nile sub-basins).

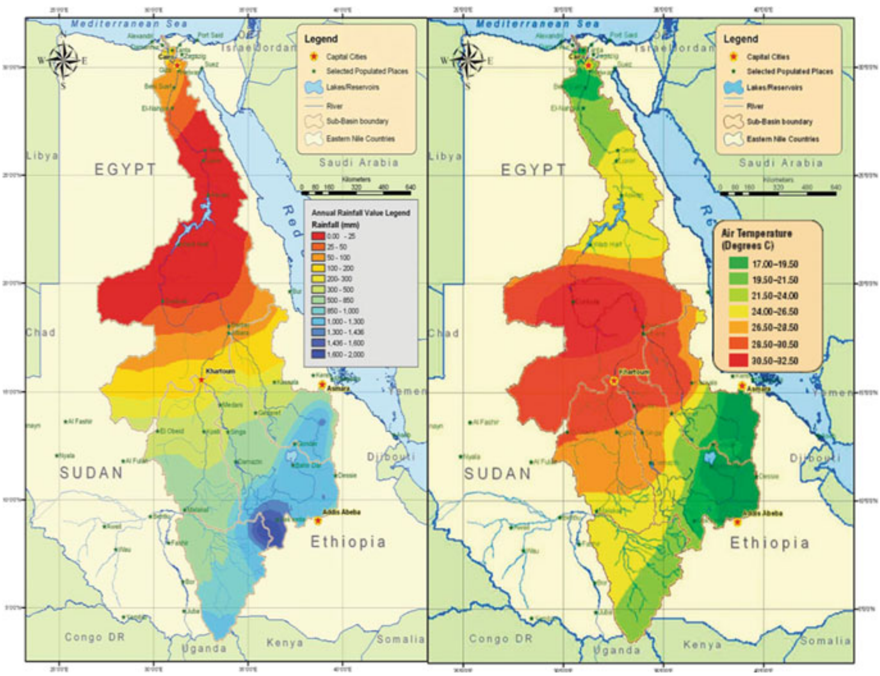

Fig. 5 Average precipitation and air temperature contours for the Eastern Nile [2]

Fig. 6 Sub-basins of Eastern Nile [2]

2.1.1 Blue Nile (Abbay RIVER) Sub-Basin

The Blue Nile sub-basin covers an estimated 342,000 km^2 [2]. This river joins the White Nile in Khartoum to become the Main. Roughly 60% of the sub-basin lies in Ethiopia, and its elevation ranges from above 4,000 M.S.L. in south Gondar to below 400 M.S.L. in Khartoum. Much of the basin (24%) lays in rugged terrain, with land slopes greater than 20%.

The climate of the sub-basin ranges from humid tropical in the southern highlands to semi-arid (Sahelian) in eastern Sudan [2]. Conway [4] reviews key references on the climatology literature for the Quaternary (i.e., the past

2 million years) in the Blue Nile [5–7] and conducts an analysis of available data for the Upper Abbey in Ethiopia. Other studies mentioned address historical fluctuations in the levels of Ethiopian Rift Valley Lakes [8, 9] which do not lay in the Blue Nile Basin but often experience similar climate conditions.

Conway [4] finds that there is relatively little seasonal variation in temperature in the Abbey River basin (3–6°C), since peak temperatures occur in April and May and summer highs are moderated by increased cloud cover in July and August. Accordingly, evapotranspiration also varies very little (50 mm between low values during the summer and high values in April and May). Average temperatures fall by 5.8°C for every 1,000 m rise in elevation, and this rate increases during the dry winter months (September to March). In fact, the traditional Ethiopian climate classification is based on three zones: the *Kolla* zone below 1,800 m (mean temperature 20–28°C), the *Woina Dega* zone 1,800–2,400 m (mean temperature 16–20°C), and the *Dega* zone above 2,400 m (mean temperature 6–16°C). Evaporation is highly dependent on elevation and does not vary greatly in the highlands; it has been estimated to be 1,500–1,800 mm/year, with the lowest values in the southwest [2]. However, as the river descends into the Sudanese plains, evaporation increases rapidly to about 4,000 mm/year at the outlet of the Roseires reservoir and 4,700 mm/year at Sennar. In the plains, rainfall and cloud cover is generally much lower, as shown in Fig. 5.

Rainfall in Ethiopia is highly seasonal and influenced by three complex, dynamic mechanisms: (1) the ITCZ, the tropical upper easterlies, and a local convergence in the Red Sea coastal region [4]. The different circulation patterns which generate (**a**) dry and (**b**) wet season conditions are shown in Fig. 7. During the *Bega* winter dry season from November to February, the ITCZ lies to the south of Ethiopia, and rainfall only occurs along the coast of the Red Sea. Cool dry air from a large Egyptian zone of high pressure produces dry conditions throughout the Abbay basin and along the Blue Nile in Sudan. Beginning in March, the general atmospheric circulation pushes the ITCZ north, bringing *Belg* ("small") rains – mostly with moist air from the Indian Ocean [11] – to the southern, central, and eastern parts of the country, especially the southwestern highlands. The Egyptian high pressure zone then strengthens in May, blocking the northward movement of the ITCZ, and dry conditions return over the central zone. The *Kremt* rainy season (with 70% of annual rainfall) begins starting in June, when the ITCZ pushes further to its most northward position at 18–20N with the humid south-west air stream coming from the Atlantic Ocean. The *Kremt* appears also to be partially fed by humid air masses from the south-east Indian Ocean monsoon [12], which passes quickly over the southern highlands and is redirected by the dominant air stream towards the north and west [4, 13]. The humid air from the Indian and Atlantic Oceans is separated by the Zaire Air Boundary. During the *Kremt* season, the upper level African Easterly Jet (AEJ) also contributes to energy and instability in the atmosphere [12]. This season lasts until the north-easterly continental airstream (Harmattan winds) is re-established in autumn.

At the stations with long-duration rainfall records; the inter-annual variability in rainfall in the Abbay basin is moderate; coefficients of variation for these

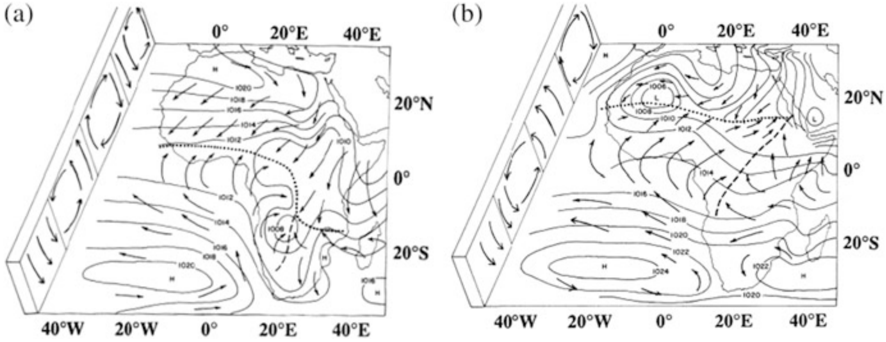

Fig. 7 Schematic of the general patterns of winds, pressure, and convergence over Africa from Nicholson [10]. *Dotted lines* indicate the ITCZ, *dashed lines*, other convergence zones. (**a**) January circulation. (**b**) July/August circulation

11 locations are generally less than 10–20%. Conway [4] found that annual rainfall among these sites tends to be highest in the southwestern part of the highlands, exceeding 2,000 mm/year in some locations, while the drier portions of the highlands, in the north-east, typically receive just over 1,000 mm/year; the overall average of the sampling sites is 1,421 mm/year for 1900–1998. These estimates are slightly higher than those using gridded data (25 km^2 resolution) and smoothing techniques (mean annual rainfall = 1,346 mm/year, with 1,900 mm/year in the south around the Didessa tributary, and about 900 mm/year in the east) [14], but closely agree with the statistics presented in the OSI [2]. Researchers have found that tropical depressions in the south-west Indian Ocean occurring in consecutive years have in the past coincided with droughts in Ethiopia, and have a particularly strong impact on March–May rainfall. However, inter-annual variation appears to be largely driven by variability in June to September rainfall, and there does not appear to be a basin-wide trend in precipitation over the period of record [4].

Below the highlands, rainfall in the Blue Nile Basin falls sharply from 1,300 mm/year round the Sudan–Ethiopia border to about 700 mm/year at the outlet of the Rosaries reservoir and 180 mm/year at Khartoum (Fig. 5), with average precipitation of roughly 570 mm/year over the entire reach [14].

2.1.2 Baro-Akobo-Sobat and White Nile Sub-Basins

To the south of the Blue Nile sub-basin see Fig. 6, the Baro-Akobo-Sobat sub-basin covers an estimated 250,000 km^2, though precise estimates vary somewhat ([2, 15–17]. The Baro travels through semi-permanent wetlands known as the Machar Marshes before flowing into the Sobat. It joins the White Nile at the outlet of the Sudd at Malakal in south-central Sudan. Roughly 40% of this sub-basin lies in the south-western portion of the Ethiopian highlands, and its elevation ranges from 3,000 to below 500 m above sea level (M.S.L.). From Malakal to the junction with the Blue Nile at Khartoum (the White Nile sub-basin, covering roughly 295,000 km^2), the elevation of the White Nile drops just 13 m over a reach of 840 km.

The upper reaches of the Baro-Akobo have a mostly tropical climate with rains lasting from late April to early November and a dry winter season. The portion of the watershed in Sudan (lower Sobat and White Nile) is characterized by a semi-arid tropical climate with a much shorter rainy season lasting less than 3 months (late June to early September). Mean annual rainfall in the Sobat sub-basin ranges from 680 to 2,200 mm/year, and rainfall then decreases steadily to below 200 mm/year at Khartoum. As in the Blue Nile sub-basin, seasonal and spatial variation in rainfall is largely governed by the north-south movement of the ITCZ. Mean annual daily temperatures increase from 17–19.5°C in the highlands to 26.5–30.5°C between Malakal and Khartoum [2]. Similarly, annual evaporation increases from 800 mm/year in the upper reaches of the Baro watershed to 1,600 mm/year at Gambella, and 3,000 mm/year at Khartoum [2, 15]. Remote sensing measurements indicate that the Machar marshes are more seasonal than previously thought, and have evaporation of about 1,300 mm/year [18].

2.1.3 Tekeze (Setite) – Atbara Sub-Basin

The Tekeze (Setite) – Atbara sub-basin covers an estimated 180,000 km^2 [2, 15, 16]. The Atbara River joins the main Nile in northern Sudan (Fig. 6). All its major tributaries originate in the north central and western highlands of Ethiopia, where roughly 80% of the sub-basin lies. The elevation of these rivers ranges from above 3,000 M.S.L. in the northern highlands to 500 M.S.L. at the Sudan–Ethiopia border and about 300 M.S.L. at the main Nile junction.

The high altitude reaches have a primarily moist sub-humid climate with a much shorter rainy season than the more southern sub-basins of the Eastern Nile, with rains lasting from late June to early September. Mean annual rainfall ranges from 675 to 1,000 mm/year; the amount is again governed by the movement of the ITCZ. This climate quickly becomes semi-arid in western Ethiopia and arid across north-eastern Sudan, where the Setite crosses the Sahara desert. Annual rainfall at the border is below 700 mm/year; this falls to 400 mm/year at the Khasm el Girba station and to a mere 20 mm/year at the Nile junction. Due to the variation in the absolute northward progression of the ITCZ, the coefficient of variability for rainfall in the sub-basin (35%) is much higher than in the southern sub-basins of the Eastern Nile (~20%). Similarly to the Blue Nile sub-basin, mean annual temperatures increase from 17–19.5°C in the highlands to over 30°C at the Nile junction [2]. Annual evaporation increases from 1,000 mm/year at Lake Tana to 3,000 mm/year at Khartoum moving south to north over the course of the sub-basin [15].

2.1.4 Main Nile from Khartoum to the Mediterranean Sea

From Khartoum, the main Nile sub-basin has an area of nearly 1,070,000 km^2. Over the course of this reach, the river gradually gets wider, as it cuts through arid desert land. Between Khartoum and Aswan, the elevation of the river slopes very gently downward from 400 to 100 M.S.L. Two hundred kilometers from the sea, the river bifurcates, forming the Nile Delta. There is very little rainfall in Northern Sudan and throughout most of the Egypt. Most of this sub-basin gets less than 50 mm/year of rain, and evaporation is quite high. Near the Mediterranean Sea, rainfall is roughly 180 mm/year, with most of the rain coming during the winter months (November to February); further south, Cairo receives only 25–30 mm/year and there is spotty or no rainfall between Cairo and the Atbara junction [15]. In northern Africa, the coefficient of variation for rainfall increases from 0.4 at the Mediterranean Coast to 4.0 in southern Egypt (reflecting the fact that rain events are very infrequent over the heart of the Sahara desert), before decreasing back to 0.4 at Khartoum. Average annual temperatures rise above 32°C in northern Sudan around Dongola, and then steadily decrease to an average around 20°C on the Mediterranean coast. In parallel with these temperature trends, evaporation decreases from 3,000 mm/year at Khartoum to 2,400 mm/year at Aswan and 1,650 mm/year at the Mediterranean.

2.2 Climate of the Southern Nile

2.2.1 Lake Victoria and the Equatorial Lakes Sub-Basin

Most of the Equatorial Lakes Plateau (catchment area of 315,500 km^2), lying between the two branches of the Rift Valley, has a dry sub-humid climate, though some parts can better be described as moist sub-humid, especially in the highlands or near Lake Victoria, which has a catchment of roughly 68,800 km^2 [19]. The Ruwenzori Mountains extending between Lakes Edward and Albert on the western side of the plateau are the highest peaks in the Nile basin, rising to more than 5,100 M.S.L. Mt. Elgon, to the north-east of Lake Victoria, has a slightly lower elevation of 4,300 M.S.L. All of the major lakes are much lower, at about 1,000 M.S.L. or lower. The Nile descends gradually to the Sudanese plains (500 M.S.L. north of the Lake Plateau) [15].

Generally speaking, rainfall over this region can occur at any time of the year and inter-annual variation is moderate (the coefficient of variation of annual precipitation amount is less than 0.2, though it can exceed 0.3 over some specific areas [20]). Peak rainfall typically occurs first in April and again in November. These peaks occur when the ITCZ crosses over East Africa. Between November and May, the rains come with the north-eastern monsoon (the Red Sea area); from May to September, they come with the south-eastern monsoon. In general, the April–May rains are more abundant, while the October–November rains are more

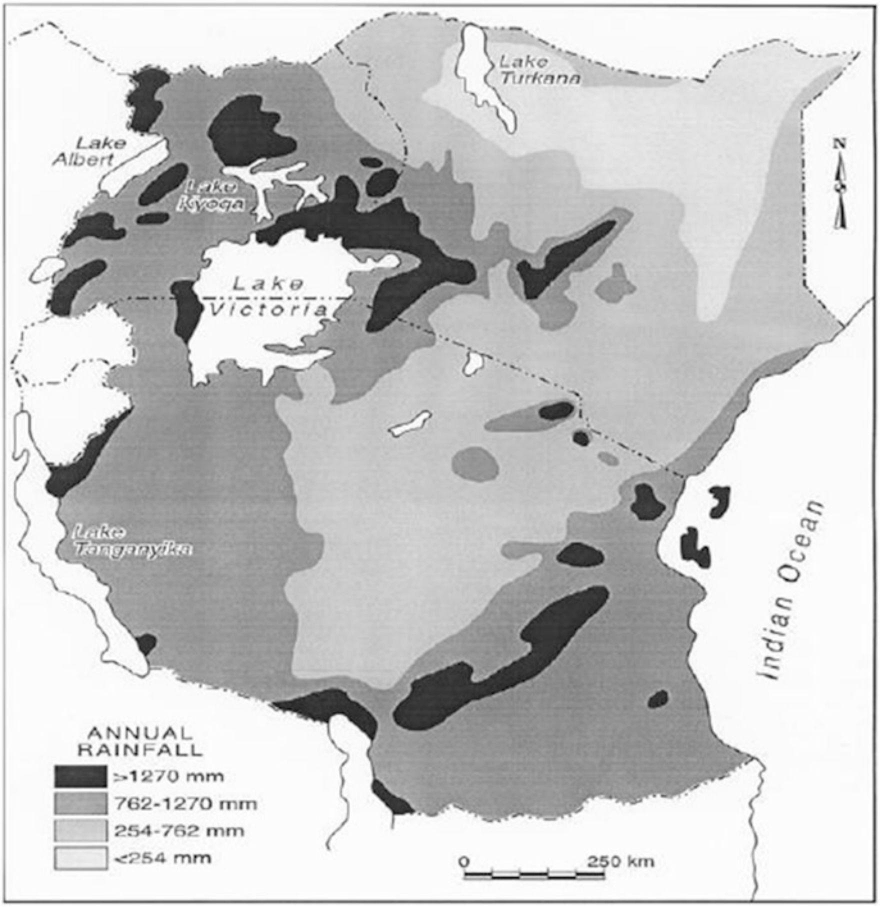

Fig. 8 The spatial distribution of rainfall near Lake Victoria (from Kiage and Liu [19])

variable, regimes with slow equatorial westerly's and ocean currents tend to lead to above average rainfall [21]. There is also substantial spatial variation in mean annual rainfall over and around Lake Victoria, as shown in Fig. 8. Rainfall directly over northwest Lake Victoria is quite high, exceeding 2,500 mm/year; while the southern side of the lake receives no more than 900–1,000 mm/year (the long-term average rainfall over the lake is about 1,765 mm/year [22]), and steep rainfall gradients down to 1,000 mm/year occur over the lands to the east of it [14, 15]. The lands to the north and north-east of Victoria and around Lakes Albert and Kyoga receive on average about 1,300–1,400 mm/year of rain.

Maximum average temperatures occur in February and October. The mean annual temperature is 19–21°C around Lake Victoria, and annual variations are low (3°C). North of Lake Victoria, average temperature rises to 24°C at the outlet of Lake Albert. As with precipitation, evaporation in the Equatorial Lakes Region varies somewhat over space. Shahin [15] presents estimates from several authors suggesting that evaporation is lowest to the west of Lake Victoria, ranging from 1,250 mm/year over Lake Edward to 2,000 mm/year at the southern end of Lake Albert and the eastern shore of Lake Victoria. Over the lake, evaporation and precipitation are nearly equal. North of Lake Victoria, evaporative demand in the Victoria Nile, and Lakes Kyoga and Albert is estimated at 2,000–2,200 mm/year.

2.2.2 Bahr el Jebel Sub-Basin

The Bahr el Jebel sub-basin covers an area of roughly 330,000 km^2 and stretches from the outlet at Lake Albert to Malakal, where the White Nile begins. The elevation drops very slowly at the beginning of the reach until Nimule in Uganda, then drops fairly quickly over 150 km to Juba, the capital of southern Sudan. A number of torrential, seasonal streams join the river in this stretch. From Juba to Malakal, the elevation of the river drops very slowly, and extensive swamps known as the Sudd flank the Bahr el Jebel on either side.

Mean annual precipitation decreases steadily as the river flows northwards, from roughly 1,400 mm/year to under 800 mm/year at Malakal [15]. In northern Uganda and southern Sudan, inter-annual variability in precipitation is modest (coefficient of variation ~0.2); to the north variability increases and rainfall is primarily restricted to one season from April to October [14]. There is some evidence that much of the moisture over the eastern part of this reach originates in the Indian Ocean, while the western portion receives more Atlantic moisture [18]. Mean annual temperatures between the southern border of Sudan and Malakal (where begins the White Nile sub-basin) are roughly 26–27°C [15]. Average temperature in the swamps is about 2°C less than outside the swamps, and the relative humidity is higher, lowering evaporation. Open-water evaporation outside the swamps and over most of the sub-basin ranges between 2,000 and 2,300 mm/year, and this range has typically been used throughout the whole Sudd area. However, evaporation is considerably reduced inside the swamps to 900–1,100 mm/year, and varies seasonally as well as spatially with changes in soil saturation. Therefore, the precise estimates of evaporation in the swamps are a matter of some debate, and there is evidence from remote sensing methods that the wetlands occupy a larger area than was previously thought [18, 23]. These methods suggest average annual evaporation of about 1,650 mm/year, though there is high inter-annual variability in these estimates (1,460–1,935 over three years).

2.2.3 Bahr el Ghazal Sub-Basin

The Bahr el Ghazal sub-basin is a shallow, unnavigable set of rivers draining an area of roughly 528,000 km^2 to the west of the Southern Nile, from which a mere trickle joins the main stem of the Bahr el Jebel at Lake No, the outlet to the Sudd swamps [15]. Most of the water from this river basin is lost to evaporation from its

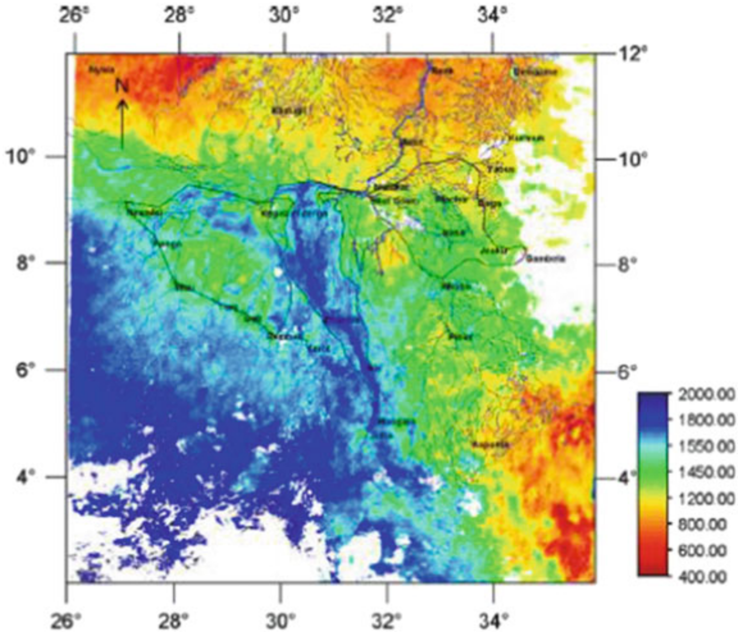

Fig. 9 Annual evaporation map for the Sudd and Bahr el Jebel (from Mohamed et al. [20])

extensive swamps. Precipitation decreases steadily going from south-west to north-east, from a maximum of about 1,550 mm/year to about 850 mm/year at Lake No and the intersection with the Bahr el Jebel. This moisture is mostly of Atlantic origin [18]. Inter-annual variation in rainfall over the Bahr el Ghazal is low (coefficient of variation of 15–20%). Figure 9 shown that evaporation is highest over the western portion of the basin (above 2,200 mm/year) and decreases as the Bahr el Ghazal merges into the Sudd swamps; throughout the basin, remote sensing methods suggest that the average is roughly 1,500 mm/year [18], which is somewhat less than the Sudd, where more soil remains saturated for longer periods of the year.

3 Variability of Nile Climate and Long-Term Historical Changes

Because of the direct influence of highly variable precipitation patterns on Nile flows, questions related to short- and long-term fluctuations in the Nile basin have long preoccupied hydrologists. Historical reconstructions of lake levels provide considerable insight into the climate conditions prevailing in the equatorial portion of the Nile basin since the early 1800s. After being relatively low for the early part of the nineteenth century, many lakes reached very high stands in the later

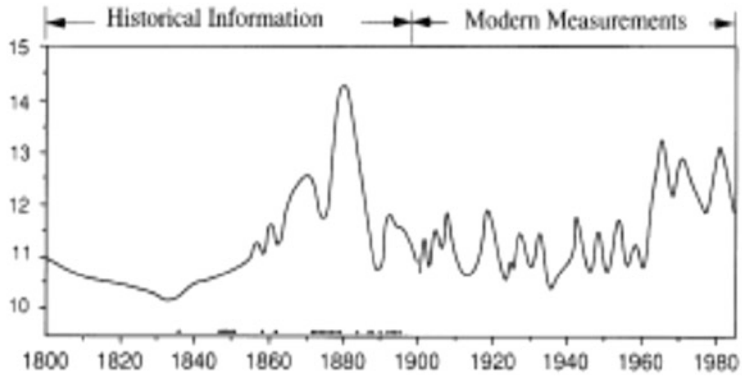

Fig. 10 Water level in Lake Victoria since 1800. Actual measurements began in 1896; preceding values are reconstructed from documentary evidence, see Nicholson [12]. Levels prior to 1850 are very approximate as they are based on minimum Nile flows in Egypt

nineteenth century; Lake Victoria provides an example (Fig. 10), but other Equatorial and Sahelian lakes (Albert, Malawi, Chilwa, and Chad) show similar patterns [22]. These high levels suggest a Nile discharge 15–35% higher than that observed in the early twentieth century, which is consistent with Nilo meter data from Cairo [24], as well as reconstructed evidence and inference presented in numerous studies [24–26]. These lake level changes were probably due to dry climate conditions followed by a wet phase with an increase in mean cloudiness, as temperature, wind speed, and evaporative changes alone cannot explain the fluctuations. A coinciding wet climate phase also occurred in West Africa in the late 1800s [27].

The sensitivity of lake levels to precipitation changes is also shown by the fact that many Equatorial Lakes rose dramatically in the 1960s. Lake Victoria rose roughly 2 m between 1961 and 1968; rainfall during this period was roughly 10% above the long-term average. The 1 m rise in 1961 coincided with rainfall of 2,486 mm/year over the lake, or 41% above the average of 1,765 mm/year [22], and only small positive anomalies over the remainder of the decade were necessary to maintain this high level. On the other hand, persistent negative rainfall anomalies between 1978 and 1986 (7% average reduction) led to a subsequent 1 m fall in the lake level. Due to their storage capacities, there tends to be a lag in the response of water level to decadal and longer-term precipitation change in the large Equatorial Lakes.

Nicholson [12] explored the spatial modes of recent short-term variability over Africa, and found that two coherent patterns commonly occur, which are consistent with fluctuations during the late Pleistocene (more than 10,000 years ago) and early to mid-Holocene (beginning 10,000 years ago). The more frequent pattern is characterized by precipitation anomalies of opposite sign prevailing in equatorial and subtropical latitudes (such as in the decade from 1950–1959, during which subtropical rainfall was high while equatorial rainfall was low, a pattern that was reversed in the decade from 1960 to 1969). The second pattern features negative anomalies over most of the continent (as in the decade from 1980 to 1989, during which positive anomalies were only found very close to Lake Victoria).

A number of studies have firmly established that sea surface temperatures (SSTs) in the Indian Ocean are the dominant sources of recent climate variability over East Africa, and that these SSTs are partially determined by the El Niño Southern Oscillation (ENSO) (Clark et al. 2003; [28–33]). Region-specific studies indicate that El Niño events (low Southern Oscillation Index (SOI) values) associated with strongly positive SST anomalies coincide with above-normal rainfall during the "short rains" (October–December) in much of equatorial East Africa, and lower summer (July–September) rainfall in the Sahel and over the Ethiopian highlands ([34–37]. For example, the very large positive rainfall anomaly that led to record levels in the instrumental period for Lake Victoria in 1878 coincided with one of the strongest El Niño events of the last few centuries [22]. On the other hand, during La Niña events (high SOI values), the effect is weaker but reversed for Ethiopia, and negative rainfall anomalies occur in October–December in Equatorial East Africa and to a lesser extent, in February–April of the year following the event [38]. Thus, in Equatorial East Africa, SST anomalies contribute mainly to rainfall variability during the short rains; with the long rains being less susceptible to these systematic influences. ENSO itself oscillates irregularly at time intervals of 3–7 years [39].

Over Ethiopia, this effect of ENSO and Indian Ocean SSTs is somewhat complicated and sometimes judged to be contradictory [40]; there is a positive correlation between regional rainfall in north-central and western Ethiopia and the Southern Oscillation Index (SOI), due to influences on south-westerly flow advection moisture from the Congo Basin. When the SOI is negative, the low pressure system, which feeds summer monsoon rainfall in East Africa, is not well developed and/or displaced to the east. Reflecting these displacements, the variability of *Kiremt* rainfall in the central and northwestern stations is high (coefficient of variation >0.3). The association with southern and eastern rainfall, which climatologists think is more strongly influenced by advection from the Indian Ocean and displays the bimodal precipitation pattern observed in Equatorial East Africa, is much lower, a finding that is bolstered by analysis of the moisture fields and wind patterns over the basin's lower altitudes [18], and analysis of variability (coefficient of variation <0.2), Camberlin [34, 35] finds associations between East African rainfall and the Indian monsoon and atmospheric pressure in Bombay that are much stronger than associations with the SOI. He concludes that active monsoon conditions enhance the Equatorial west-east pressure gradient, strengthening winds that bring moisture from the Congo Basin to Ethiopia and East Africa.

Another system that figures prominently in discussions about East African variability is the Indian Ocean Dipole, or IOD (also sometimes called the Indian Ocean Zonal Mode or IOZM), which refers to the sum of Indian Ocean SST variations. Climatologists traditionally considered these to be an artifact of the ENSO system, pointing to strong correlations of Indian Ocean SSTs with the SOI over the past 150 years [39]. Only recently has the IOD been identified as a unique

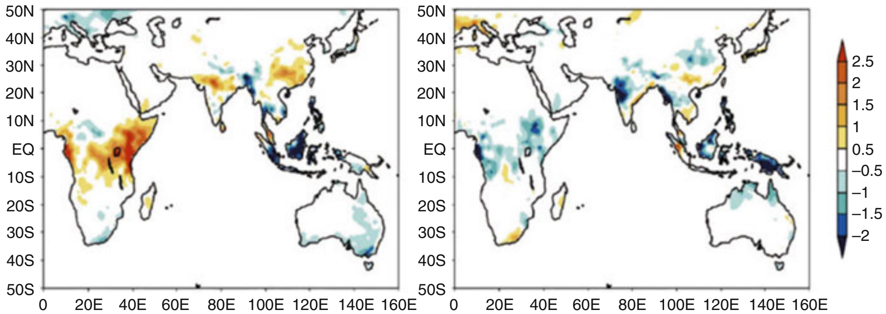

Fig. 11 Composite rainfall anomalies (mm/day) for September–November during (*left*) pure IOD and (*right*) pure ENSO events. The rainfall anomalies for the period 1958–1999 are derived from University of Delaware gridded precipitation analysis; years used in the composites of pure IOD and pure ENSO are taken from Yamagata et al. [43] (from Marchant et al. [39])

ocean-atmosphere mode [41], and there is considerable debate about its independence [42]; a positive event is characterized by anomalously warm western Indian Ocean SSTs and cold eastern Indian Ocean SSTs, as well as increased convective activity just off the coast of East Africa. In the past, this gradient was usually overlooked, and warm SSTs were broadly considered to be strictly associated with El Niño events. As shown in Fig. 11, the magnitude of the secondary rainfall maximum from October to December in East Africa is even more strongly correlated with positive IOD events than with negative ENSO (or El Niño) events [39, 44]; these results are consistent with what Sun et al. [20] find when comparing composite maps of wet and dry years.

In Sudan and the Sahel, the presence of steep rainfall gradients means that slight shifts in normal atmospheric circulation can cause major droughts, as occurred during the 1970s and 1980s [45]. Climatological work suggests that higher SSTs in the Indian Ocean may contribute to negative rainfall anomalies in the Sahel (as they do on average over Ethiopia), but SST patterns do not consistently produce expected anomalies, and variability changes abruptly from decade to decade [12].

Indian Ocean SSTs and Atlantic atmospheric circulation; specifically, cool North Atlantic SSTs, clearly play an important role in rainfall decreasing at west Africa and extend to rainfall deficit in in the highlands of Ethiopia as well ([36]). Furthermore, there is an inter-annual, decadal persistence in rainfall deficits in the Sahel which suggests the possibility of land-atmosphere feedbacks in this region in addition to the influence of long-lasting north-south gradients in Atlantic SSTs [12]. Still, hypotheses that drought frequency increases in the Sahel are due primarily to land use change have recently fallen out of favor ([46], p. 866).

Indeed, research suggests that small shifts in atmospheric circulation are quite common in the Nile basin, and provides justification for the observed ENSO and SOI linkages with Eastern Nile precipitation. The physical basis for the argument is as follows. First, the ITCZ itself shifts based on a set of factors that include the earth's orbiting axis, variations in the position of the sun, and the strength of radiative forcing from the sun [47]. Second, the ENSO phenomenon induces SST changes, which alter ocean circulation as well as movement of the ITCZ, thereby influencing tropical climate patterns; for example, higher SSTs lead to drier conditions over many subtropical regions during El Niño. Third, ENSO may play a role in triggering or pre-disposing the system for particular IOD conditions [48, 49], which plays a prominent role in inter-annual variability by inducing a strong zonal gradient in tropical sea surface temperatures [41, 49]). Indeed, Indian Ocean temperatures tend to begin to rise about 5 months following ENSO events [50] and the strongest recent IOD episode was during the El Niño in 1997–1998. Still, some researchers contest specific aspects of this argument, pointing to the large IOD episode that occurred independently of an ENSO event in 1961 and led to very high lake stands in the Equatorial Region, (see Fig. 11.), as well as 11 out of 19 other "moderate to strong" episodes [41].

The particularly strong climate anomaly that took place in 1997/98, with the wettest October and November on record over much of the region (400 mm above average rainfall), remains only partially understood. During this El Niño (which alone cannot explain the observed anomalies) and positive IOD event, warming across the western equatorial Indian Ocean was extreme, and these conditions led to advection of moist and highly unstable air into Equatorial East Africa [28]. There were catastrophic floods throughout East Africa, and many of the Equatorial Lakes rose dramatically in conjunction with this event; water levels in Lake Victoria increased ~1.7 m, similarly to the event that took place in 1961 [51, 52].

Quinn [53] attempted to correlate longer-term SOI behavior with the Roda gauge in Cairo as a proxy for East African rainfall and found the record of below normal flood levels at Cairo to be associated with low or negative SOI behavior (El Niño events, and therefore lower average rainfall in Ethiopia). Whetton and Rutherford [54] analyzed data from 1587 onward and argued that Nile floods were significantly lower than average in El Niño years, but that a relationship with the SOI has only become strong since 1830. Eltahir [55] finds a correlation of about −0.5 between an averaged September–November ENSO SST index and Nile flows at Aswan (see Fig. 12).

Lake levels and the Roda gauge at Cairo also provide most of the indirect evidence for longer-term climatic shifts over East Africa. These records are reconstructed from a variety of sources (hydrological, sedimentary, and historical documents), and they generally support the hypothesis that northern and eastern Africa have in the past experienced rapid and sudden changes, and suffered regularly from sustained periods of drought. A number of researchers discuss the conditions that led to formation of the Nile, and evaluate the long record of Roda gauge measurements ([15]).

While exploring the history of Nile flows and formation of the modern river, Hurst [11] originally explored the role of long-term climate variations in the Nile

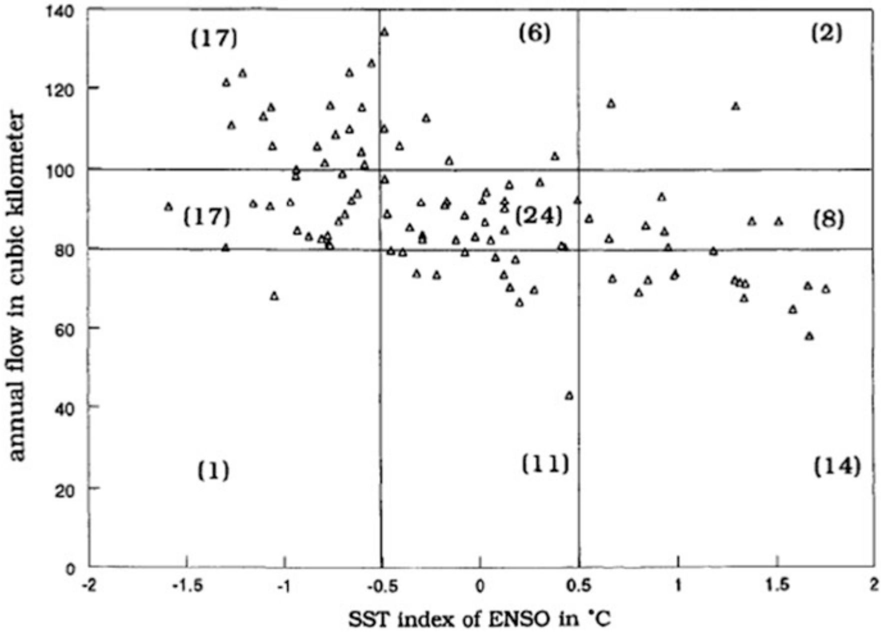

Fig. 12 Categories of Nile flood at Aswan and ENSO SST index from Eltahir [55]; warm SSTs are associated with El Niño events and reduced Nile flows, due to the decreased rainfall over Ethiopia and the Sahel

basin relying on fossilized evidence and remains of man-made tools found on terraces found at different heights in the lakes of the Equatorial Region, indicating fluctuating water levels. Similar findings have since been presented more recently by other researchers [45]. A number of geologists and paleo-limnologists have also analyzed climatic variability, and some discuss its spatial variability; they use evidence from lake sediments and other sources to conclude that northern and eastern Africa, and the Sahel region, have experienced substantial droughts lasting from decades to centuries, some of which were far more severe than any of the droughts recorded in the twentieth century ([19]). Attempts to link these dry periods to solar variations have not been conclusive, particularly given the reliance on solar proxies. In addition, it has not been demonstrated that these droughts can be simulated with coupled ocean-atmosphere models ([46], p. 483).

4 The Impacts of Climate Change on Growth and Development

The impacts of climate change at the Nile basin are not evenly distributed – the poorest countries and people will suffer earliest and most. If and when the damages appear it will be too late to reverse the process. Thus we are forced to look a long way ahead. Climate change is a grave threat to the developing world and a major obstacle to continued poverty reduction across many dimensions as described below.

First, developing regions are at a geographic disadvantage: they are already warmer, on average, than developed regions, and they also suffer from high rainfall variability. As a result, further warming will bring poor countries high costs and few benefits.

Second, developing countries – in particular the poorest – are heavily dependent on agriculture, the most climate-sensitive of all economic sectors, and suffer from inadequate health provision and low-quality public services.

Third, low incomes and vulnerabilities make adaptation to climate change particularly difficult. Because of these vulnerabilities, climate change is likely to reduce further already low incomes and increase illness and death rates in developing countries. Falling farm incomes will increase poverty and reduce the ability of households to invest in a better future, forcing them to use up meager savings just to survive.

At the national level, climate change will cut revenues and raise spending needs, worsening public finances. Climate-related shocks have sparked violent conflict in the past, and is a serious risk in areas such as West Africa, the Nile basin, and Central Asia. Section 4 highlights possible climate impacts for some vital sectors.

4.1 Water

People will feel the impact of climate change most strongly through changes in the distribution of water around the world and its seasonal and annual variability. As the water cycle intensifies, billions of people will lose or gain water. Some risk becoming newly or further water stressed, while others will see increases in water availability. Seasonal and annual variability in water supply will determine the consequences for people through floods or droughts. Melting glaciers and loss of mountain snow will increase flood risk during the wet season and threaten dry-season water supplies to one-sixth of the world's population (over one billion people today).

Table 1 Annual number of deaths related to climate change component (death/% total)

Disease/illness	Annual deaths (million)	Climate change component (death % total)
Diarrhea diseases	2.0	47.000/2%
Malaria	1.1	27.000/2%
Malnutrition	3.7	77.000/2%
Cardiovascular disease	17.5	Total heat/cold data not provided
HIV/AIDS	2.8	No climate change element
Cancer	7.6	No climate change element

Source: WHO [56] based on data from Patz et al. [57]. The numbers are expected at least double to 300,000 deaths each year by 2030

4.2 Food

In tropical regions, even small amounts of warming will lead to declines in yield. In higher latitudes, crop yields may increase initially for moderate increases in temperature but then fall. Higher temperatures will lead to substantial declines in cereal production around the world, particularly if the carbon fertilization effect is smaller than previously thought, as some recent studies suggest declining crop yields are likely to leave hundreds of millions without the ability to produce or purchase sufficient food, particularly in the poorest parts of the world. Ocean acidification, a direct result of rising carbon dioxide levels, will have major effects on marine ecosystems, with possible adverse consequences on fish stocks.

4.3 Health

Climate change will increase basin-wide deaths from malnutrition and heat stress. Vector-borne diseases such as malaria and dengue fever could become more widespread if effective control measures are not in place. In higher latitudes, cold-related deaths will decrease. Table 1 presents the annual number of deaths related to the climate change component (death/% total) and it is predicted that the numbers of deaths are expected to at least double to 3,000,000 deaths each year by 2030 [56]. Moreover, Table 2 shows potential impacts of climate change at Nile basin with health interlink ages.

4.4 Land

Sea level rise will increase coastal flooding, raise costs of coastal protection, lead to loss of wetlands and coastal erosion, and increase saltwater intrusion into surface and groundwater. The homes of tens of millions more people are likely to be affected by flooding from coastal storm surges with rising sea levels. People in

Table 2 Potential impact of climate change at Nile basin with health interlink ages (Source: AEO2)

Sub-region	Human health interlink age
Northern Basin	Sea level rises lead to salt intrusion, flooding, and destruction of human settlements and water Stress • Over-abstraction of scarcer water leads to deteriorating water quality and higher incidences of waterborne diseases • Unpredictable weather conditions lower food yields and quality • Depleted fish stocks lower food security and household incomes • Temperature rises affect the health of vulnerable populations, e.g., children, the sick, and elderly
South and East Basin	• Rising numbers of EWEs lead to severe food shortages and malnutrition • Rising numbers of EWEs lead to higher morbidity and mortality • Warmer ambient temperatures extend weather-sensitive diseases, e.g., malaria and Rift valley fever to previously disease-free zones such as the highlands of Ethiopia, Kenya, Rwanda, and the United Republic of Tanzania • Frequent flooding favors the spread of waterborne diseases, e.g., cholera, Rift valley fever, and parasitic infections • More severe drought leads to conflicts over scarcer natural resources, e.g., water, forests, and pastures

south and east Asia will be most vulnerable, along with those living on the coast of Africa and on small islands. Some estimates suggest that 150–200 million people may become permanently displaced by the middle of the century due to rising sea levels, more frequent floods, and more intense droughts.

4.5 *Infrastructure*

Damage to infrastructure from storms will increase substantially from only small increases in event intensity. Changes in soil conditions (from droughts or permafrost melting) will influence the stability of buildings.

4.6 *Environment*

Climate change is likely to occur too rapidly for many species to adapt. One study estimates that around 15–40% of species face extinction with 2°C of warming. Strong drying over the Amazon, as predicted by some climate models, would result in dieback of forest with the highest biodiversity on the planet.

4.7 Non-Linear Changes and Threshold Effects

Warming will increase the risk of triggering abrupt and large-scale changes. Melting or collapse of polar ice sheets would accelerate sea level rise and eventually lead to substantial loss of land, affecting around 5% of the global population. Warming may induce sudden shifts in regional weather patterns that have severe consequences for water availability in tropical regions [58].

5 Possible Climate Impacts and Variability on River Nile Basin

Climate change and variability are likely to impose additional pressures on water availability, water accessibility, and water demand in Nile basin (Table 3). Even without climate change, several countries in Africa, particularly in northern Africa, will exceed the limits of their economically usable land-based water resources before 2025. The population at risk of increased water stress in Africa is projected to be between 75–250 million and 350–600 million people by the 2020s and 2050s, respectively [59]. Due to heavy human extraction and high evaporation, the Nile River basin and its inhabitants are especially sensitive to climate change. Along its 3,000 km course through arid northern Sudan and Egypt, the Nile loses a huge amount of water due to evaporation. This makes water supply extremely sensitive to temperature and precipitation changes.

Analysis of rainfall and river-flow records during the twentieth century demonstrates high levels of inter-annual and inter decadal variability. This is experienced locally and regionally in the headwater regions of the Nile and internationally through its effects on downstream Nile flows in Sudan and Egypt. Examples of climate variability are presented from areas in the basin where it exerts a strong influence on society; the Ethiopian highlands (links with food security), Lake Victoria (management of non-stationary lake levels), and Egypt (exposure to inter decadal variability of Nile flows). The mean annual rainfall over the basin is 1,200 mm and reaches about 1,500 mm at the high lands; 70–75% of the annual rainfall occurs during June–September. The second rain period is February–May [1].

Historical records of Nile floods reveal a strong correlation between low Nile floods and cold summers in Europe, and conversely, high Nile floods and warms summers in Europe. Fluctuations in Nile flood levels coincide with climatic changes in the Sahel and even the flow of the Senegal River at the other end of Africa.

Warmer temperatures increase evapotranspiration which in turn cause higher precipitation, leading to higher Nile floods. Climate change clearly influences the size of Nile floods. The long-term annual average of Nile flows between “1872 and 1986” is approximately 88 km^3/year. The floods typically occur between the

Table 3 Possible climate impact at different sectors [50]

Temp rise (°C)	Water	Food	Health	Land	Environment	Abrupt and large-scale impacts
1°C	Small glaciers in the Andes disappear completely, threatening water supplies for 50 million people	Modest increases in cereal yields in temperate regions	At least 300,000 people each year die from climate-related diseases (predominantly diarrhoea, malaria, and malnutrition) Reduction in winter mortality in higher latitudes (Northern Europe, USA)	Permafrost thawing damages buildings and roads in parts of Canada and Russia	At least 10% of land species facing extinction (according to one estimate) 80% bleaching of coral reefs, including Great Barrier Reef	Atlantic thermohaline circulation starts to weaken
2°C	Potentially 20–30% decrease in water availability in some vulnerable regions, e.g., Southern Africa and Mediterranean	Sharp declines in crop yield in tropical regions (5–10% in Africa)	40–63 million more people exposed to malaria in Africa	Up to 10 million more people affected by coastal flooding each year	15–40% of species facing extinction (according to one estimate) High risk of extinction of Arctic species, including polar bear and caribou	Potential for Greenland ice sheet to begin melting irreversibly, accelerating sea level rise, and committing world to an eventual 7 m sea level rise
3°C	In Southern Europe, serious droughts occur once every 10 years 1–4 billion more people suffer water shortages, while 1–5 billion gain water, which may increase flood risk	150–550 additional millions at risk of hunger (if carbon fertilization weak) Agricultural yields in higher latitudes likely to peak	1–3 million more people die from malnutrition (if carbon fertilization weak)	1–170 million more people affected by coastal flooding each year	20–50% of species facing extinction (according to one estimate), including 25–60% mammals, 30–40% birds, and 15–70% butterflies in South Africa Onset of Amazon forest collapse (some models only)	Rising risk of abrupt changes to atmospheric circulations, e.g., the monsoon Rising risk of collapse of West Antarctic Ice Sheet

4°C	Potentially 33–50% decrease in water availability in Southern Africa and Mediterranean	Agricultural yields decline by 15–35% in Africa, and entire regions out of production (e.g., parts of Australia)	Up to 80 million more people exposed to malaria in Africa	7–300 million more people affected by coastal flooding each year	Loss of around half Arctic tundra Around half of all the world's nature reserves cannot fulfill objectives	Rising risk of collapse of Atlantic thermohaline circulation
5°C	Possible disappearance of large glaciers in Himalayas, affecting one-quarter of China's population and hundreds of millions in India	Continued increase in ocean acidity seriously disrupting marine ecosystems and possibly fish stocks		Sea level rise threatens small islands, low-lying coastal areas (Florida) and major world cities such as New York, London, and Tokyo		
More than 5°C	The latest science suggests that the Earth's average temperature will rise by even more than 5 or 6°C if emissions continue to grow and positive feedbacks amplify the warming effect of greenhouse gases (e.g., release of carbon dioxide from soils or methane from permafrost). This level of global temperature rise would be equivalent to the amount of warming that occurred between the last age and today – and is likely to lead to major disruption and large-scale movement of population. Such "socially contingent" effects could be catastrophic, but are currently very hard to capture with current models as temperatures would be so far outside human experience					

Note: This table shows illustrative impacts at different degrees of warming. Some of the uncertainty is captured in the ranges shown, but there will be additional uncertainties about the exact size of impacts (more detail in Box 3.2). Temperatures represent increases relative to pre-industrial levels. At each temperature, the impacts are expressed for a 1°C band around the central temperature, e.g., 1°C represents the range 0.5–1.5°C, etc. Numbers of people affected at different temperatures assume population and GDP scenarios for the 2080s from the Intergovernmental Panel on Climate Change (IPCC). Figures generally assume adaptation at the level of an individual or firm, but not economy-wide adaptations due to policy intervention (covered in Part V) months of July–September. Figure 13 is a graphical representation of the average monthly Nile flows and a record of annual Nile flows at Aswan between 1872 and 1986.

Mohamed Abdelati predicts that through the analysis of different GCMs and emission scenarios for 2030, that the probability of wetting (increase of precipitation rates) is higher than drying in the extreme scenario case. The precipitation change showed that there will be spatial precipitation change on the Nile basin where the range of precipitation change on the Blue Nile will range from −2.14% to 10.65% and the White Nile precipitation will change within a range of −1.43% to 9.94%. There is a wide disparity in predictions of future Nile flow scenarios. Figure 13 shows summaries of a few of these predictions.

Rosenzweig et al. [60] used a hydrological model coupled with GCM-based climate change scenarios for doubled global atmospheric concentrations (2xCO2) to find changes in runoff. There is widely diverging pictures of possible future Nile flows: GISS (Goddard Institute for Space Studies, New York, NY) – a 30% increase; UKMO (United Kingdom Meteorological Office) – a 12% decrease; and GFDL (Geophysical Fluid Dynamics Laboratory steady-state, Princeton, NJ) – a 78% decrease. These are postulated for the year 2060.

Conway and Hulme [61] suggest that currently anticipated changes in atmospheric concentrations of CO_2 by year 2025 would lead to an air temperature increase of 1°C across the Nile basin, leading to increased evaporation loss and slight increase (2%) in rainfall in the Blue Nile basin and slightly larger increase in rainfall (5%) over the Equatorial Lakes region, spread fairly evenly through wet and dry seasons.

Strzepek and Yates [62] found that Nile water resources declined under GFDL and increased for the GISSA and UKMO scenarios. Strzepek and Yates [63] supports previous findings that changes in precipitation, and to a lesser extent temperature, over the Nile basin could have serious consequences on regional water resources throughout this large African basin. The 2xCO2 GCM scenarios gave a wide range of changes both in total water yield at Aswan and regional hydrologic changes throughout the basin. Five of six GCMs showed increased flows at Aswan, with increases as much as 137% (UKMO). Only one GCM (GFDLT)

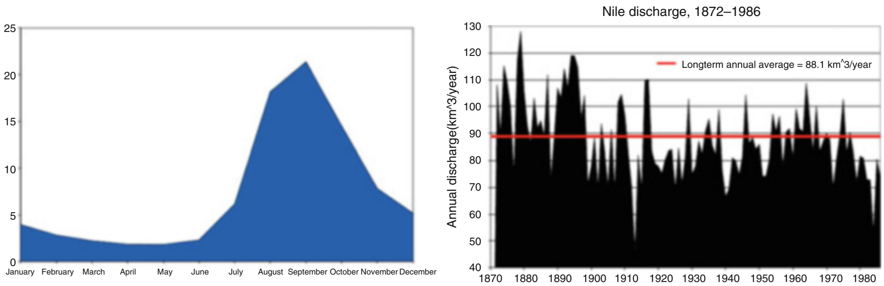

Fig. 13 Average long-term monthly and annually Nile flows, 1872–1986

showed a decline in annual discharge at Aswan (−15%). Five of six GCMs predict increased precipitation in equatorial Africa.

The net basin supply of Lake Victoria is a true measure of climatic variability around the lake, whereas the lake level and outflow time series are not independent, and are influenced by storage effects in the lake, which can persist for the order of a decade (Fig. 14). A first estimate of the annual net basin supply can be obtained from the annual storage changes in the lake and the mean annual outflow. Observations suggest that the surface area of the lake only varies by a few percent about a mean value of 67,000 km^2, so annual storage changes can be estimated by assuming a constant surface area equal to the mean. End-of-year levels have been estimated by assuming that the annual mean values calculated by the model are indicative of mid-year levels, and assuming a linear variation in levels between years. Comparing the period 1870–1996, studies showed that, during the 1878 event, both the rainfall and net basin supply rose rapidly to an exceptional level, but fell back to very low values in the next two years. This is in contrast to the 1917 event, which built up over two to three years, and the 1961–1964 events, which arose initially from a rapid increase in rainfall, which was almost sustained for the next two to three years, and was followed by several years of above average rainfall. These three major events were therefore all qualitatively different, and the anecdotal evidence confirms this to some extent: i.e., the 1878 event arose from exceptional rainfall, affecting both the Blue and White Nile basins; the 1917 event arose from heavy rainfall to the north of the lake, with unusually high flows in the Pibor; whilst the 1961–1964 event arose from prolonged heavy rainfall in the Lake Victoria region, but not in the Blue Nile catchment. The smaller increase in levels during the 1890s appears to have been due to several years of slightly above average rainfall. It is also worth noting that, for all these events, the variations in a real rainfall are not particularly large, with a total range of only 1,400–2,400 mm year over the period 1870–1998. However, due to the extreme sensitivity of levels to minor changes in rainfall, in terms of levels and outflows, these events appear much more dramatic than suggested by the rainfall data. The statistical characteristics of the rainfall and

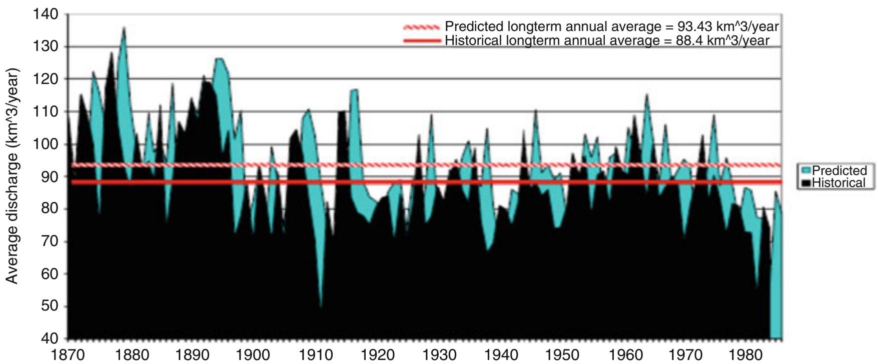

Fig. 14 Historical Nile discharge (1872–1986) vs. predicted Nile discharge, (predicted long-term annual average = 93.43 km^3/year and historical long-term annual average = 88.4 km^3/year

net basin supply are summarized for several averaging periods, using the standard WMO 30-year periods. In the period 1871–1900, the lake rainfall appears to have been slightly above average, and perhaps slightly more variable than usual. Only the years 1961–1990 stand out as having unusually high rainfall. The estimated maximum lake rainfall and lake levels reached are also shown; according to the model, the lake rainfall reached comparable peaks of 2,300–2,400 mm in 1878 and 1961, but a much lower peak in 1917.

Annual mean levels in 1878 and 1961 were also similar. However, following the 1961 event, levels took much longer to decline due to the sustained increase in rainfall, and the lake levels more clearly exhibited the quasi-exponential decline expected from idealized models of the lake water balance (e.g.,). In all stochastic models for net basin supply, the frequency distribution gives a useful first indication of the likely range of predicted levels. In terms of future levels, a preliminary conclusion in some studies was that additional 26 years of data (1870–1895) did not greatly change ideas about the natural flow regime of the lake, and stochastic projections of future flows are likely to be similar to previous estimates. The additional 26 years of data therefore provided further evidence that Lake Victoria levels are highly variable, and can both rise and fall rapidly in periods of only a few years. Also, the 1961–1964 event, which at the time was a major surprise to those involved with development of the Nile, can be seen to be consistent with the natural rainfall regime of the region, with a return period which can be tentatively estimated as of the order of 100 years.

With regard to the coastal intrusion, although two countries of the Nile basin, namely Egypt and Sudan, have access to coastal areas on the Mediterranean (for Egypt) and the Red Sea (for Egypt and Sudan), the Nile River basin itself interacts with coastal areas only in Egypt at the Mediterranean Sea where the Nile River forms it Nile Delta at its utmost downstream end. The Northern coastal areas of Egypt that are within the Nile Delta are inhabited by over 20 million people which represent about 30% of the population of Egypt and about 15% of the total Nile basin population. These socio-economic activities in the Nile Delta are dependent mainly on agriculture, in addition to other fishery and industrial activities.

The coastal interaction of the Nile Delta with the Mediterranean Sea at the downstream end of the Nile River makes the Delta area vulnerable to many risks including impacts of sea water rise due to climate change, coastal sea shore erosion, sea water intrusion to groundwater, potential flooding incidents in case of high Nile floods, and associated High Aswan Dam releases, in addition to potential pollution of coastal areas and resulting Nile water and sea water quality degradation downstream a 6,000 km river, affecting quality of life, fishery, and tourism in coastal areas.

The ever increasing water demand in the extremely arid regions of the Nile basin like Egypt and northern part of Sudan which are dependent mainly on the Nile has resulted in the dire need to regulate the Nile flow at its downstream to make use of every drop of water. The several dams and regulating structures on the Nile have slightly reduced to some extend the flow of sediments reaching the coastal areas of the Nile Delta which slightly may increase the risk of coastal shore erosion at the interaction zone between the Nile and the Mediterranean Sea. Several measures have been taken in Egypt to protect the coastal areas and the people living along the Nile from some of the above mentioned risks, including institutional measures such as regulation for enforcing a safe zone from coastal areas and establishing a sector for Shore Protection within the Ministry of Water Resources and Irrigation of Egypt, limiting rice cultivation areas to northern areas to help push sea water interface away to protect the groundwater water aquifer from sea water intrusion, as well as limiting groundwater pumping in coastal areas to reduce potential upcoming and sea water intrusion. Other infrastructure measures include installation of breakwaters, channel improvement to the Main Nile Delta branches (Damietta and Rosetta), installation of tail end barrages to prevent backing of sea water into Nile River branches during low Nile flow seasons. The impacts of climate change on sea water rise can have a great impact on the low lands of the coastal areas in the Nile Delta where a large population may be affected and forced to relocate.

6 Conclusions

Throw the above finding in this chapter, the following points could be concluded:

- Flooding may intensify in many Nile basin regions, even in areas where total precipitation is projected to decline.
- Short-term (seasonal or shorter) droughts are expected to intensify in most of Nile basin regions. Longer-term droughts are expected to intensify in large areas of the eastern Nile.
- Annual precipitation and river-flow increases are observed now in the west of the delta and the northwest regions. Very heavy precipitation events have increased nationally and are projected to increase in all regions as a result of extremes events. The length of dry spells as well is projected to increase in most areas, especially the eastern portions of the Basin.
- Climate change is expected to affect water demand, groundwater withdrawals, and aquifer recharge, reducing groundwater availability in some areas especially at Egypt Nile valley and delta.
- Sea level rise, storms and storm surges, and changes in surface and groundwater use patterns are expected to compromise the sustainability of coastal freshwater aquifers and wetlands.
- Increasing air and water temperatures, more intense precipitation and runoff, and intensifying droughts can decrease river and lake water quality in many ways, including increases in sediment, nitrogen, and other pollutant loads.
- Climate change affects water demand and the ways water is used within and across regions and economic sectors. Egypt and Sudan are particularly vulnerable to changes in water supply and demand due to climate changes and potential development project at Blue Nile.

- Changes in precipitation and runoff, combined with changes in consumption and withdrawal, have reduced surface and groundwater supplies in many areas. These trends are expected to continue, increasing the likelihood of water shortages for many uses.
- Increasing flooding risk affects human safety and health, property, infrastructure, economies, and ecology in many regions across the Nile basin.

References

1. Strzepek K, McCluskey A (2007) The impacts of climate change on regional water resources and agriculture in Africa. Policy research working paper series. The World Bank, 62p
2. ENTRO (2006) One-system inventory report no. 125. Addis Ababa, Ethiopia, Eastern Nile Technical Region Office
3. Conway D, Mould C, Bewket W (2004) Over one century of rainfall and temperature observations in Addis Ababa, Ethiopia. Int J Climatol 24(1):77
4. Conway D (2000) The climate and hydrology of the upper blue Nile River. Geogr J 166(1):49
5. Messerli B, Winiger M (1980) The Saharan and East African uplands during the Quaternary. In: Williams MAJ, H Faure (eds) The Sahara and the Nile. A. A. Balkema, Rotterdam, p 87
6. Williams MAJ, Faure H (1980) The Sahara and the Nile. A.A. Balkema, Rotterdam
7. Williams MAJ, Adamson DA (1981) A land between two Niles. A.A. Balkema, Rotterdam
8. Gillespie R, Street-Perrott AF, Switsur R (1983) Post-glacial and glacial episodes in Ethiopia have implications for climate prediction. Nature 306:680
9. Street-Perrott AF (1982) Twentieth century fluctuations in lake level in the Ziway-Shala Basin, Ethiopia. Palaeoecol Afr 14:99
10. Nicholson S (1996) A review of climate dynamics and climate variability in Eastern Africa. In: Johnson TC, Odada EO (eds) The limnology, climatology and paleoclimatology of the East African lakes. Gordon and Breach Publishers, Amsterdam, pp. 25–56
11. Hurst HE (1952) The Nile: a general account of the river and the utilization of its waters. Constable Publishers, London
12. Nicholson S (2000) The nature of rainfall variability over Africa on time scales of decades to millennia. Global Planet Change 26(1):137
13. Mohamed Y, Hurk BVD, Savenije H (2005) Hydro climatology of the Nile: results from a regional climate model. Hydrol Earth Syst Sci Discuss 2:319
14. Roskar J (2000) Assessing the water resources potential of the Nile River based on data, available at the Nile forecasting center in Cairo. Hydrometeorological Institute of Slovenia, Ljubljana, 50p
15. Shahin M (1985) Hydrology of the Nile Basin. Elsevier Science Publishers, Amsterdam
16. Sutcliffe JV, Parks YP (1999) The Hydrology of the Nile. International Association of Hydrological Sciences, Oxford Shire
17. TAMS/ULG (1997) Baro-Akobo River Basin integrated development master plan study. Final Report, Vol. I Executive summary, Submitted to Federal Democratic Republic of Ethiopia. Ministry of Water Resources
18. Mohamed Y, Bastiaanssen W, Savenije H (2004) Spatial variability of evaporation and moisture storage in the swamps of the upper Nile studied by remote sensing techniques. J Hydrol (Amsterdam) 289(1/4):145
19. Kiage LM, Liu K (2006) Late quaternary paleoenvironmental changes in East Africa: a review of multi proxy evidence from palynology, lake sediments, and associated records. Prog Phys Geogr 30(5):633–658

20. Sun L, Semazzi F, Giorgi F (1999) Application of the NCAR regional climate model to Eastern Africa. Part I: simulations of autumn rains of 1988. J Geophys Res 104:6529
21. Hastenrath S (2001) Variations of East African climate during the past two centuries. Clim Change 50(1):209
22. Nicholson S, Yin X (2001) Rainfall conditions in Equatorial East Africa during the nineteenth century as inferred from the record of Lake Victoria. Clim Change 48(2):387
23. Mohamed Y, Savenije H, Bastiaanssen W (2005) New lessons on the Sudd hydrology learned from remote sensing and climate modeling. Hydrol Earth Syst Sci Discuss 2:1503
24. Davies H, Walsh R (1997) Historical changes in the flood hazard at Khartoum, Sudan: lessons and warnings for the future. Singap J Trop Geogr 18(2):123
25. Grove, A. (1972) Climatic change in Africa in the last 20000 years. Les Problems de Development du Sahara Septentrional (Development Problems of Northern Sahara, in French)
26. Hastenrath S, Kutzbach J (1983) Paleoclimatic estimates from water and energy budgets of East African lakes. Q Res 19:141–153
27. Nicholson S (2001) Climatic and environmental change in Africa during the last two centuries. Clim Res 17(2):123
28. Goddard L, Graham NE (1999) Importance of the Indian Ocean for simulating rainfall anomalies over eastern and Southern Africa. J Geophys Res 104:19099
29. Indeje M, Semazzi HFM, Ogallo LJ (2000) ENSO signals in East African rainfall seasons. Int J Climatol 20(1):19
30. Korecha D, Barnston A (2007) Predictability of June–September rainfall in Ethiopia. Mon Weather Rev 135(2):628
31. Mutai CC, Ward MN, Colman AW (1998) Towards the prediction of the East Africa short rains based on sea-surface temperature-atmosphere coupling. Int J Climatol 18(9):975
32. Yu LS, Rienecker MM (1999) Mechanisms for the Indian Ocean warming during the 1997–1998 El Niño. Geophys Res Lett 26:735
33. Clark CO, Webster PJ, Cole JE (2003) Interdecadal variability of the relationship between the Indian Ocean zonal mode and east African coastal rainfall anomalies. J Clim 16:548
34. Camberlin P (1995) June-September rainfall in north-eastern Africa and atmospheric signals over the tropics: a zonal perspective. Int J Climatol 15(7):773
35. Camberlin P (1997) Rainfall anomalies in the source region of the Nile and their connection with the Indian summer monsoon. J Clim 10(6):1380
36. Camberlin P, Janicot S, Poccard I (2001) Seasonality and atmospheric dynamics of the teleconnection between African rainfall and tropical sea-surface temperature: Atlantic vs. ENSO. Int J Climatol 21(8):973
37. Schreck CJI, Semazzi FHM (2004) Variability of the recent climate of eastern Africa. Int J Climatol 24(6):681
38. Nicholson SE, Selato JC (2000) The influence of La Nina on African rainfall. Int J Climatol 20 (14):1761
39. Marchant R, Mumbi C, Behera S, et al. (2007) The Indian Ocean dipole the unsung driver of climatic variability in East Africa. Afr J Ecol 45(1):4
40. Nyssen J, Vandenreyken H, Poesen J (2005) Rainfall erosivity and variability in the Northern Ethiopian Highlands. J Hydrol 311(1–4):172
41. Saji NH et al. (1999) A dipole mode in the tropical Indian Ocean. Nature 401:360
42. Goddard L, Mason SJ, Zebiak SE, et al. (2001) Current approaches to seasonal to interannual climate predictions. Int J Climatol 21(9):1111
43. Yamagata T, Behera S, Luo J, et al. (2004) Coupled ocean-atmosphere variability in the tropical Indian Ocean. In: Wang C, Xie SP, Carton JA (eds) Earth climate: the ocean–atmosphere interaction, Geophysical monograph, vol 147, pp. 189–211
44. Xie SP et al. (2002) Structure and mechanisms of South Indian Ocean climate variability. J Clim 15:864
45. Evans, T. (1990) History of Nile flows. In: Howell PP, Allan JA (eds) The Nile. School of Oriental and African Studies, Royal Geographical Society, London/Cambridge University Press, Cambridge, pp 5–39

46. IPCC 2007 Climate change 2007: Synthesis report. Fourth assessment report (AR4). An assessment of the intergovernmental panel on climate change (IPCC), Geneva
47. Collins M, Frame D, Sinha B, et al. (2002) How far ahead could we predict El Niño? Geophys Res Lett 29(10):492
48. Allan RP et al. (2001) Is there an equatorial Indian Ocean dipole, and is it independent of the El Niño Southern oscillation? CLIVAR Exchanges. 21 1
49. Webster PJ (1999) Coupled ocean-atmosphere dynamics in the Indian Ocean during 1997–98. Nature 401:356
50. Trenberth KE et al. (2002) The evolution of ENSO and global atmospheric temperatures. J Geophys Res 107:4065
51. Birkett CM, Murtugudde R, Allan JA (1999) Indian Ocean climate event brings floods to East Africa's lakes and Sudd marsh. Geophys Res Lett 26:1031
52. Mistry VV, Conway D (2003) Remote forcing of East African rainfall and relationships with fluctuations in levels of Lake Victoria. Int J Climatol 23(1):67
53. Quinn WH (1992) A study of Southern oscillation-related climatic activity for AD 622–1900 incorporating Nile River flood data. In: Diaz HF, Margrave V (eds) El Niño: historical and pale climatic aspects of the Southern oscillation. Cambridge University Press, Cambridge, p. 119
54. Whetton P, Rutherfurd I (1994) Historical ENSO tele connections in the eastern hemisphere. Clim Change 28(3):221
55. Eltahir E (1996) El Niño and the natural variability in the flow of the Nile River. Water Resour Res 32(1):131
56. WHO (2005) Air quality guidelines; global update 2005. World Health Organization. Available: http://www.who.int/phe/health_topics/outdoorair_aqg/en/. Accessed 21 July 2011
57. Patz JA, Githeko AK, McCarty JP, Hussein S, Confalonieri U, de Wet N (2003) Climate change and infectious diseases. In: McMichael AJ, Campbell-Lendrum DH, Corvalán CF, Ebi KL, Githeko A, Scheraga JD, Woodward A (eds) Climate change and health: risks and responses. World Health Organisation, Geneva. http://www.who.int/globalchange/publications/climchange.pdf
58. Stern Review (2006) The economic of climate change. www.sternreview.org.uk
59. IPCC (2007) Climate change 2007: The physical basis of climate change: contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge
60. Rosenzweig C, Parry M, Fischer G (1995) World food supply. In: Strzepek K, Smith J (eds) As climate changes: international impacts and implications. Cambridge University Press, Cambridge, p. 27
61. Conway D, Hulme M (1996) The impacts of climate variability and future climate change in the Nile Basin on water resources in Egypt. Int J Water Resour Dev 12(3):277
62. Strzepek KM, Yates D (1996) Economic and social adaptations to climate change impacts on water resources: a case study of Egypt. Int J Water Resour Dev 12(2):229
63. Strzepek KM, Yates DN (1996) Assessment of water resources vulnerability and adaptation to climate change. Int J Water Resour Dev 12(2):111

Climate Changes Vulnerability and Adaptive Capacity

Khaled Khir-Eldien and Sherien Ahmed Zahran

Abstract Climatic changes have affected and will continue to affect human health, water supply, agriculture, transportation, energy, coastal areas, and many other sectors of society, with increasingly adverse impacts on the Nile Basin Riparian economy and quality of life.

Observed and projected climate change impacts vary across the regions of the Nile Basin. Selected impacts emphasized in the region are shown, and many more are explored in detail in this chapter. Water quality and quantity are being affected by climate change. Such changes in precipitation and runoff, combined with changes in consumption and withdrawal, have reduced surface and groundwater supplies in many areas. These trends are expected to continue, increasing the likelihood of water shortages for many uses. Water quality is also diminishing in many areas, particularly due to sediment and contaminant concentrations after heavy downpours. Sea level rise, storms and storm surges, and changes in surface and groundwater use patterns are expected to compromise the sustainability of coastal freshwater aquifers and wetlands. In most of the basin regions, water resources managers and planners will encounter new risks, vulnerabilities, and opportunities that may not be properly managed with existing practices. Meanwhile, using scientific information to prepare for climate changes and different climate models techniques in advance can provide economic opportunities, and proactively managing the risks can reduce impacts and costs over time. All of these items have been addressed in this chapter.

K. Khir-Eldien (✉)
Environment and Climate Research Institute (ECRI), National Water Research Center (NWRC), Cairo, Egypt
e-mail: kzurich22@gmail.com

S.A. Zahran
Climate and Environment Risk Assessments Laboratory (CERAL), Environment and Climate Research Institute (ECRI), National Water Research Center (NWRC), MWRI, Cairo, Egypt
e-mail: shereinzahran@gmail.com

A.M. Negm (ed.), *The Nile River*,
Hdb Env Chem (2017) 56: 567–596, DOI 10.1007/698_2016_117,

Keywords Adaptive strategies, Climate models, Climate vulnerability

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Acronyms and Abbreviations

AOGCM	Atmosphere-Ocean General Circulation Model
AR4	Fourth Assessment Report of the Intergovernmental Panel on Climate Change (2007)
AR5	Fifth Assessment Report of the Intergovernmental Panel on Climate Change
CERAL	Climate and Environment Risk Assessments Laboratory
ECRI	Environment and Climate Change Research Institute
DCF	Delta change factor
ENSO	El Niño Southern oscillation
ENTRO	Eastern Nile Technical Regional Office
GCM	Global Circulation Model
GPCC	Global Precipitation Climatology Center
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Inter-Tropical Convergence Zone
IOD	Indian Ocean Dipole
IOZM	Indian Ocean Zonal Mode
NBI	Nile Basin Initiative
NCAR	National Center for Atmospheric Research
NFS	Nile Forecast System
NWRC	National Water Resources Center
RACMO	Regional Atmospheric Climate Model
RCM	Regional Climate Model
RCPs	Representative Concentration Pass Ways
SOI	Southern Oscillation Index
SRES	Special Report on Emissions Scenarios
SAR	Second Assessment Report
SST	Sea Surface Temperature
TAR	Third Assessment Report of the Intergovernmental Panel on Climate Change (2001)

1 Introduction

The Nile, which is the home and source of livelihood to approximately 160 million people, is the longest river in the world having a total length of about 6,700 km, traversing an extremely wide band of latitude, from 4° south to 32° north. The area draining into the Nile river system, about 3 million km^2 extends over 11 African countries.

The Nile Basin is subject to intra- and inter-annual variability of rainfall. Due to seasonal variability of rainfall, especially in the Ethiopian highlands, the intra-annual variability of runoff of rivers originating in the Ethiopian plateau is very high. The level of Lake Victoria is also extremely sensitive to moderate changes in rainfall over the lake and its tributaries. Average lake rainfall and evaporation are the main factors affecting the lake balance and are more or less equal. It is home to a diversity of ecosystems that include river systems, high mountains, tropical forests, woodlands, savannas, high and low altitude wetlands, arid lands, and deserts.

Rivers and their floodplains have generated and, if managed properly, can continue to generate substantial economic, environmental, and social benefits for their inhabitants. Local communities depend to a large extent on ambient water resources for household uses, and for irrigating home gardens and village irrigation plots. Rivers, streams, and lakes not only offer an environment for aquatic species, but also are often bordered by wetlands such as reed beds, floodplains, and marshes, which are known to harbor a rich assemblage of species, and are also important for the diversity of adjacent ecological communities.

This chapter discusses the tools used to predict and analyze climate changes in the basin in addition to the key factors that increase the vulnerability of the Nile Basin riparian and corresponding adaptation strategies to cope with impact of climate changes and variability. Such factors include heavy reliance on agriculture and natural resources for household, limited technologies, already water poor countries may become water stresses or scarcity, prevalence of dray lands, limited capacity of government to cope with these impact, or lake of access to capital, insurances cover, and safety net especially after weather crises.

2 AOGCM, RCMS, and Analytical Methods Used for Nile Climate Simulations

Climate models vary in complexity from simple models, which provide predictions of global mean temperature and sea level rise, such as those used in the IPCC, Second assessment report (SAR), to coupled ocean-atmosphere general circulation models (AOGCMs or GCMs for short) used to simulate the spatial and temporal variability of climate. Within this hierarchy, climate models vary in four different ways [1].

The number of spatial dimensions in the model: typically in AOGCMs, physical variables (temperature, humidity, etc.) are represented by average values over a three-dimensional grid with a ground resolution of several hundred kilometres and a different number of layers for the atmosphere and the ocean. Simpler models might have average values in one or more dimensions.

The level and extent of parameterization contains many physical processes, such as cloud formation, hydrological processes, and land use changes, occur on spatial scales smaller than the grid resolution of climate models, which creates a need to formulate the effect of sub-grid processes in the larger scale grid. Detailed models of sub-grid processes are computationally too expensive to be included in climate models. More complex and higher resolution climate models have more processes explicitly included and less need for parameterization of sub-grid processes. Reducing the number of dimensions represented in a model will require more parameterization.

The computational cost of the model: simple climate models are computationally more efficient than more complex models so they are suited to investigate a large number of scenarios. However, they only produce global trends; therefore, GCMs are needed to complete the global picture.

The comprehensive nature of the model is evident through the variety and the number of the climate components and processes represented. Some models may try to simulate the atmosphere only, while a more comprehensive model would include all the climate system components and most of the processes.

Many Atmosphere-Ocean General Circulation Models (AOGCMs) generate somewhat contradictory predictions, especially when it comes to changes in precipitation [2]. Furthermore, there have been many attempts to couple results from these various climate model simulations with hydrological models commonly used to analyze the water resources of the Nile.

Studies on climate change impacts have shown the potential for very significant changes in the flow of the Nile [3]. Estimate that flow in the Blue Nile in 2025 could range from an increase of 15% to a decrease of 9% [4]. Estimate that by 2020, the flow coming into the High Aswan Dam (HAD) could decrease by 10–50%. More recently, used bias-corrected statistical downscaling of 17 GCMs to estimate an average reduction in flow of the Blue Nile of 15% by the end of the century, and a range of change from a decrease of 60% to an increase of 45% [5], these results are displayed in Table 1. Bias-corrected statistical downscaling of 11 GCMs found a change in flow at the HAD ranging from a decrease of 32% to an increase of 15%. These researchers used the estimates of change in flow from Elshamy et al. [6] in their calculations of change in water supplies. The Third National Call (TNC) notes that lower flows in the Nile would negatively affect Egypt's economy through impacts on agriculture, industry, tourism, hydropower generation, navigation, fish farming, and the environment. High flows, while increasing the total supply of water resources, would also necessitate more expenditure on infrastructure for increased water storage and conveyance and to control flooding.

There are a growing number of Regional Climate Models (RCMs) being used for the Nile Basin that operates on a more precise scale than the AOGCMs described

Table 1 Model-simulated flow of projections of Blue Nile flow at Diem (BCM) [5]

GCM	1961–1990	2081–2100	% change
BCM	48.96	37.34	−24
CGCM	50.57	20.70	−59
CGCM63	50.82	20.38	−60
CNRM	52.24	44.80	−14
CSIRO30	47.99	34.96	−27
CSIRO35	46.66	34.96	−25
CM20	46.45	28.85	−38
CM21	47.46	34.31	−28
AOM	48.44	49.33	2
GOAL	47.65	50.86	7
INMCM	42.82	56.45	32
MIROCH	47.74	47.74	0
MIROCM	46.93	68.25	45
ECHAM	44.18	35.74	−19
MRI	50.30	33.00	−34
CCSM	32.84	40.15	22
PCM	48.60	35.38	−27
Mean	47.10	39.82	−15

above, which is promising for addressing some of their limitations. RCMs can allow up to one order of magnitude improvement in horizontal resolution (resolution is usually about 50 × 50 km), and permit more sophisticated modeling of atmospheric circulation patterns. Mohamed et al. [7] describe use of the first coupled climatic and hydrologic model for the Nile, in which a hydrological routing model is driven by rainfall and the energy influencing evaporation (as generated in the Regional Atmospheric Climate Model [RACMO]). A land-atmosphere feedback is created by allowing runoff to re-enter the atmosphere over the large wetlands in southern Sudan, and its role in the simulated regional water cycle is assessed using observational data. The results appear realistic, generating a moisture recycling ratio of 8–14% depending on the season. The model does overestimate runoff, especially in the White Nile sub-basin, and does not perfectly reproduce peak precipitation for the Blue Nile or the magnitude of the short rains over the White Nile as observed in Global Precipitation Climatology Center (GPCC) data. The authors point out that this model can also be used for evaluating water resources development proposals likely to impact the Sudd and other Nile Basin wetlands; for instance, it is estimated that a completed Jonglei canal would conserve 4 bcm/year of water and lead to a negligible change in regional rainfall since the Sudd only provides 1% of the volume of atmospheric moisture flux over the Nile [8].

Another RCM nested within a GCM and based on the National Center for Atmospheric Research (NCAR) Regional Climate Model (RegCM2) has been customized for the Lake Victoria system and coupled with the lake hydrology. The model accurately simulates large-scale circulation characteristics and seasonal effects as well as local climate features arising from complex terrain, diversity of vegetation, and presence of lakes. The simulated features include the diurnal pattern of the lake/land breeze circulation around Lake Victoria. Consistent with the important associations between rainfalls, ENSO, the IOD, and Indian Ocean SSTs detected using statistical models, precipitation anomalies appear to follow large-scale circulation anomalies.

The UK Met Office PRECIS regional climate model was configured for a large window covering the Nile Basin and the sources of moisture feeding the region. Thus, the boundaries of RCM extend far beyond the River Nile Basin and therefore the results obtained are applicable to other parts of the region as well. PRECIS was driven by an ensemble of 6 GCM experiments selected from a larger set of 17 HadCM3 ensemble members produced though perturbation of the unresolved physics for the QUMP project. The performance of the seventeen GCM ensemble members was assessed against 4 criteria; their ability to represent accurately (1) precipitation across East Africa, (2) precipitation across West Africa, (3) the Indian monsoon, and (4) temperature over the Nile Basin. The 6 GCM ensemble members were selected to obtain a good representation of the variability with just a few ensemble members. The purpose for that is to reduce the number of RCM ensemble members to reduce the computational resources required to run these simulations. The NFS basin-wide hydrological model was then used to assess changes in flows of the Nile at important stations on the outlets of the Blue Nile, the Atbara, White Nile, and the main Nile at Dongola based on the climate signal obtained from the RCM in terms of delta change factors (DCFs). In addition, the original output of the same 6 QUMP members was used to calculate DCFs at the coarser resolution on the GCM. The results indicated that the RCM ensemble has a smaller range of uncertainty compared to previous studies with modest changes in rainfall and PET. The GCM ensemble showed a much wider range than obtained from the RCM and what was reported in previous studies. The resulting changes in flows as projected by the RCM ranged between −6% to 29% for the Blue Nile at Diem and −12% to +10% for the White Nile at Malakal. Larger and positive changes were reported for the Atbara sub-basin. The resultant changes for the main Nile at Dongola, just upstream of Lake Nasser, show a positive signal between −0.5% and 36%. The GCM-based results (i.e., without downscaling) showed much larger changes in rainfall and flow with shifts in peak times at the different locations. The patterns of change for temperature were broadly similar between the GCM and RCM ensembles but the rainfall patterns were less consistent and this resulted in large ranges that have been reflected in even larger changes for flows. The joint use of a selected ensemble of GCM runs downscaled using an RCM and a hydrological model represents an affordable and practical approach for climate change impact assessments that also provides an estimate of the confidence level associated with the predictions. Without downscaling, GCM results have a much wider range of uncertainty. This emphasizes the need to downscale the results before being used in climate impact studies. Downscaling does not only provide finer resolution or details for change patterns but also reduces the range of uncertainty that is mainly caused by the coarse resolution of the GCM (Figs. 1, 2, 3, 4, and 5).

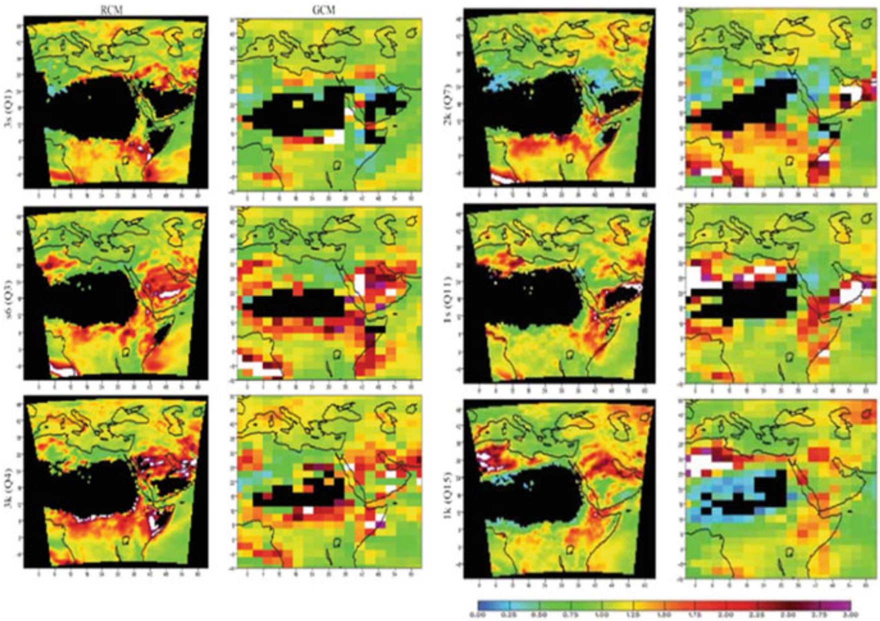

Fig. 1 Precipitation DCFs over the Nile Basin domain for January from by the RCM and GCM ensembles

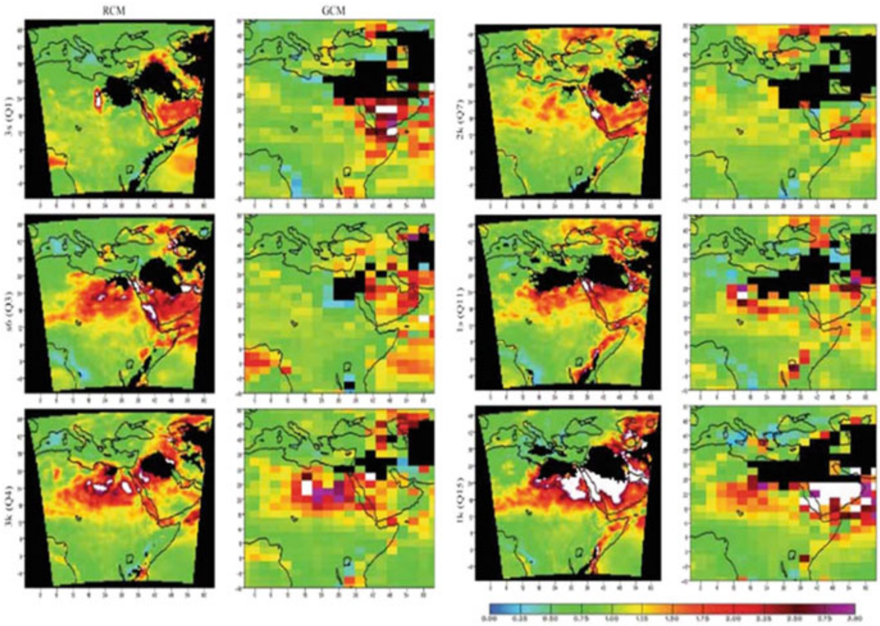

Fig. 2 Precipitation DCFs over the Nile Basin domain for August from by RCM and GCM ensembles

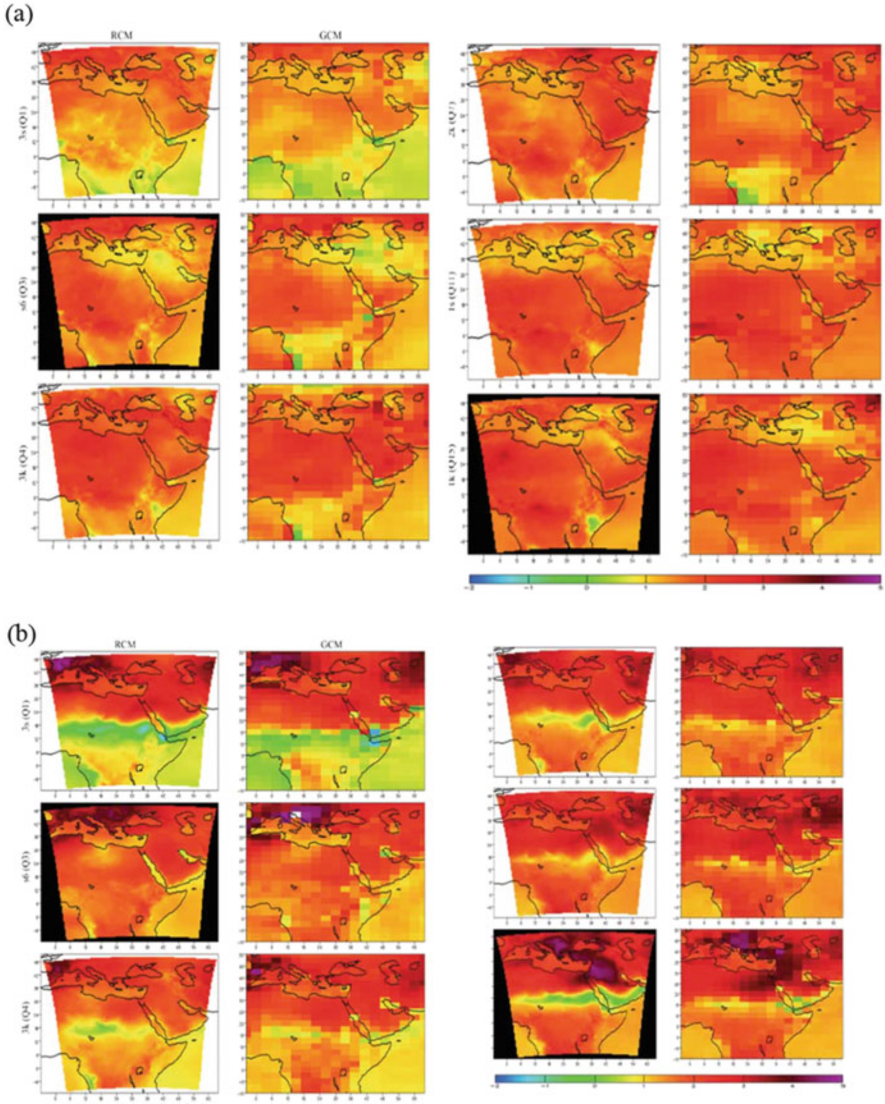

Fig. 3 Temperature DCFs over Nil Basin domain for (**a**) January and (**b**) August from by the RCM and GCM ensembles, white areas are off the scale. DCF around indicate no change

Black areas are excluded from the calculations. Precipitation is almost zero, white areas are off the scale (DCF > 3); DCF around 1 indicates no change.

Many Studies have been conducted at the Climate and Environmental Risk Assessments Laboratory (CERAL) that is hosted at the Climate Change Research Institute, National Water Research Center, dealing with statistical and dynamical downscaling for GCM models. One of these studies discussed the future variability

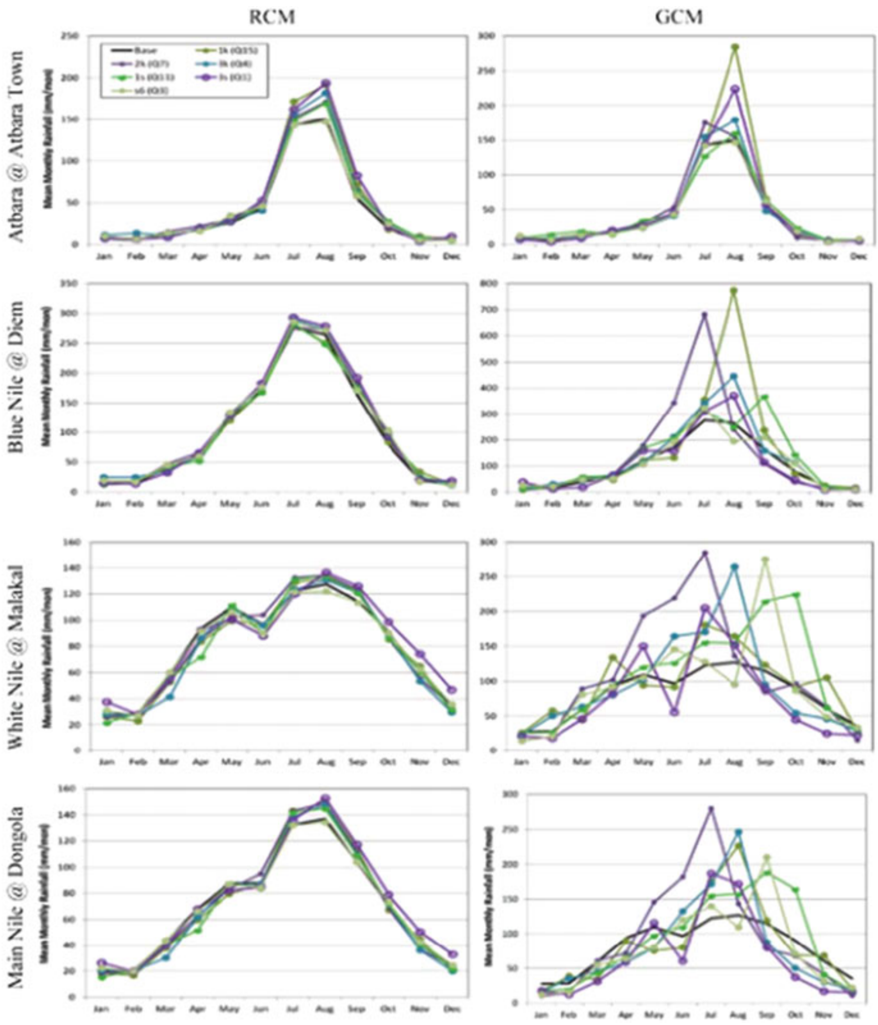

Fig. 4 Seasonal precipitation distributions for Key Nile sub-basin from the RCM and GCM ensembles

for the projection at 2050 and 2100 under the new storyline scenarios of different radiative forces that IPCC-AR5 2014 has addressed (RCP 4.5 and RCP 8.5). The outputs of the ensembles for 40 GCMs models have been analyzed and corrected using statistical downscaling. The results show that the variability of the future projections of temperature increased between (31.8 to 14.9) and (32.3 to 15.4) for scenario RCP 4.5 at 2050 and 2100, respectively, with percentage of the change around (1.565%:1.2%) and (2.07%:1.599%). For scenario RCP 8.5 the results show

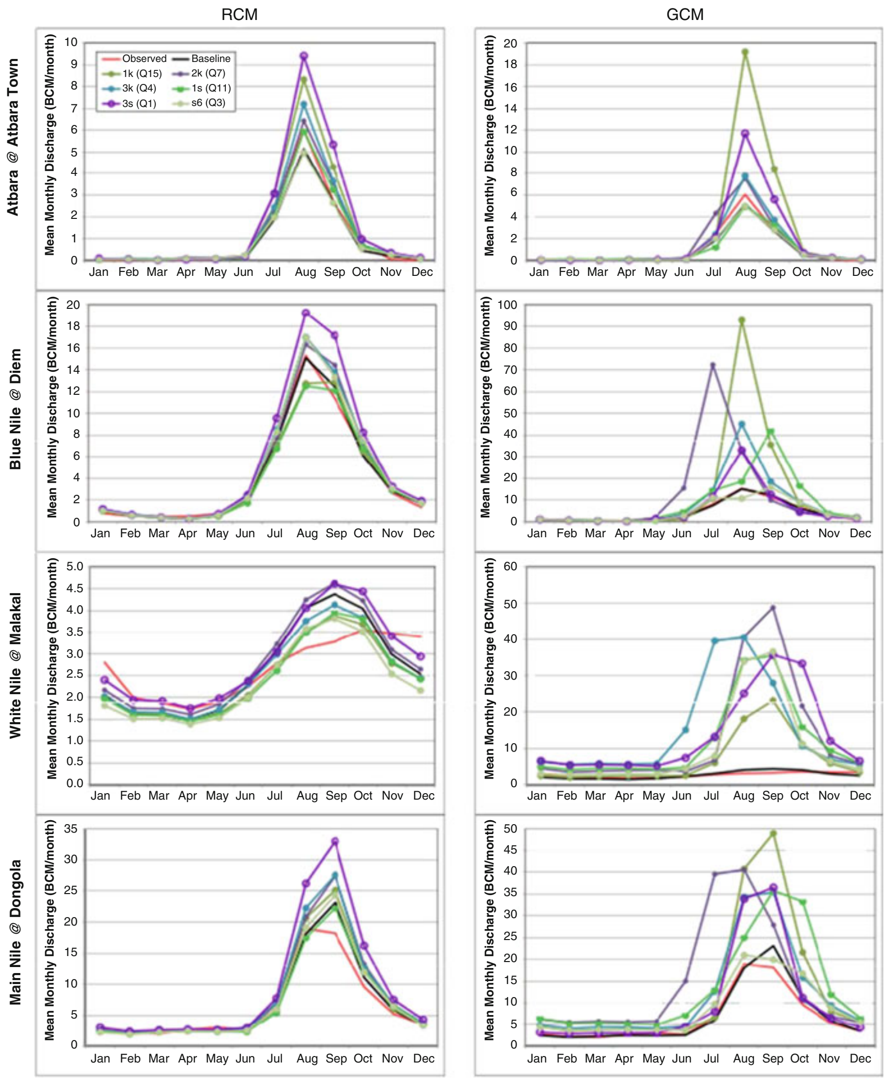

Fig. 5 Seasonal flow changes at key Nile stations from the RCM and GCM ensembles

that the increasing of temperatures will be around (32.3:16.5) and (35.2:18.2) at 2050 and 2100, with percentage of the change between (2.15%:1.66%) and (5.15%:3.9%); as shown in Tables 2 and 3 in addition to Figs. 6 and 7. Consequently, the value of precipitation at scenarios RCP 4.5 will be within the range of (1953:93.52) and (1969:5.56) at 2050 and 2100, respectively, with the percentage of change between (37.2%:−8.2%) and (46.34%:−10.78%). Whenever for scenario

Table 2 Nile Basin percentage of change of precipitation and temperatures for scenarios RCP 4.5 and RCP 8.5 radiation forces at 2050 and 2100 "Ensembles of 40 GCMs Models" (Source: [9])

	Radiative force (RCP 4.5)		Radiative force (RCP 8.5)	
Decade	Low	High	Low	High
2050	−8.2%	37.2%	−11.2%	51.0%
2100	−10.78%	46.34%	−27.01%	122.29%
	Temperatures			
Decades	Radiative force (RPC 4.5)		Radiative force (RPC8.5)	
	Low	High	Low	High
2050	1.2%	1.565%	1.66%	2.15%
2100	1.599%	2.07%	3.9%	5.15%

Table 3 Nile Basin-wide temperatures and precipitation for scenarios 4.5 and 8.5 radiation forces at 2050 and 2100 "Ensembles of 40 GCMs Models" [9]

Decade	Radiative force (RCP 4.5)		Radiative force (RCP 8.5)	
	Temperatures (°C)			
	Low	High	Low	High
2050	14.9	31.8	16.5	32.3
2100	15.4	32.3	18.2	35.2
	Precipitation (mm)			
	Low	High	Low	High
2050	5.3	1,953.93	1,971.28	5.61
2100	5.56	1,969		

RCP 8.5 the values were (1971.2:561) at 2050 and 2100, respectively, with the percentage of change between (51.1%:−11.2%) and (122.29:−27.01%), as shown in Tables 2 and 3 and Figs. 8 and 9.

3 Climate Changes Challenges at Nile Basin

Most of the Nile Basin countries are among the poorest in the world. Many of the countries still rely on subsistence-level rain-fed agriculture for food production, thus remain vulnerable to frequent impacts of recurrent drought. Egypt and Sudan, countries that are predominantly arid or semiarid, largely depend on the waters of the Nile for food production through irrigated agriculture. As the population of the basin countries grow, which is estimated to be 300 million and is expected to double every 25 years, it is anticipated that the pressure on the river and its ecosystems will grow substantially.

The environmental resources of the Nile Basin are subject to threats which are of significant consequences for future development of the Basin. Such threats include land degradation, loss of wetlands resulting in loss of biodiversity, deterioration of

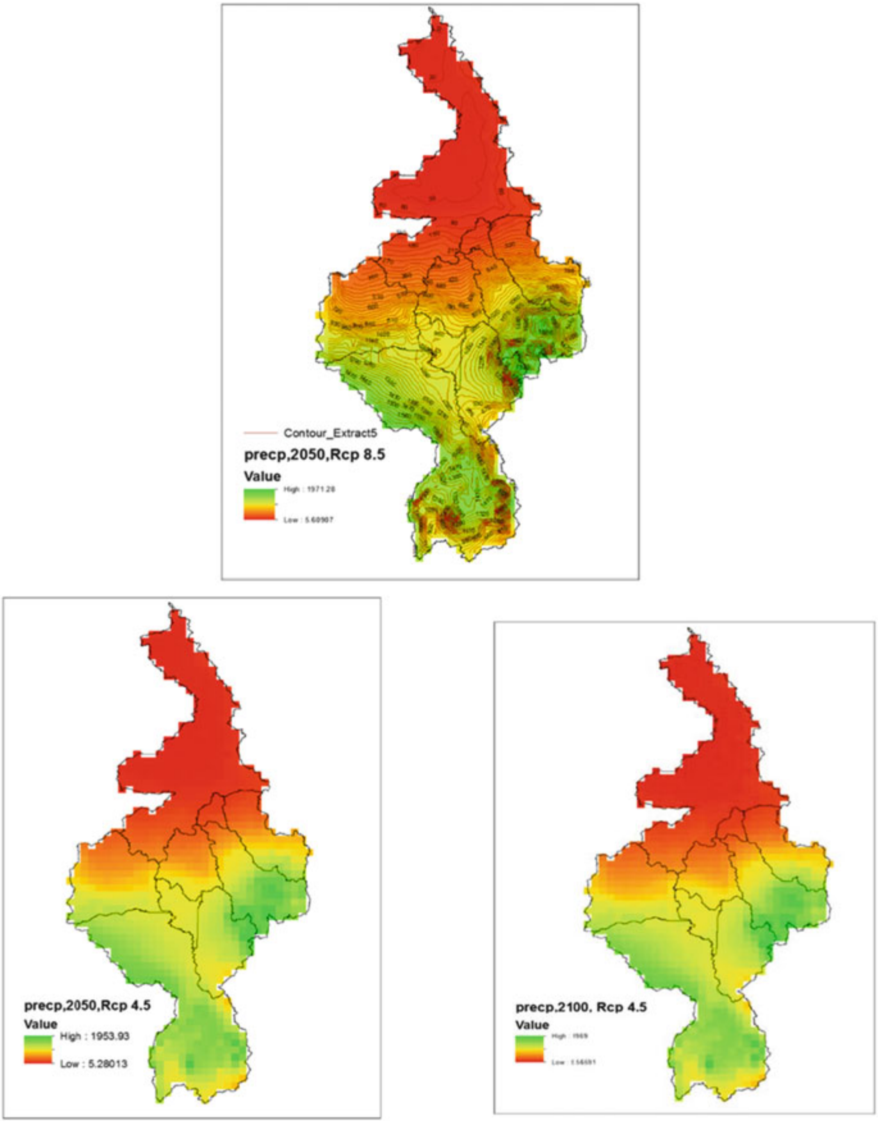

Fig. 6 Nile Basin temperatures using ensembles (40 GCMs) models RCP 4.5 and RCP 8.5 for 2050 and 2100 (Source: [9])

water quality, and natural disasters, such as droughts and floods. Such threats impact different parts of the basin to a varying degree, see Table 4.

The key factors that increase the vulnerability of Nile Basin's population to the impacts of climate change and variability include:

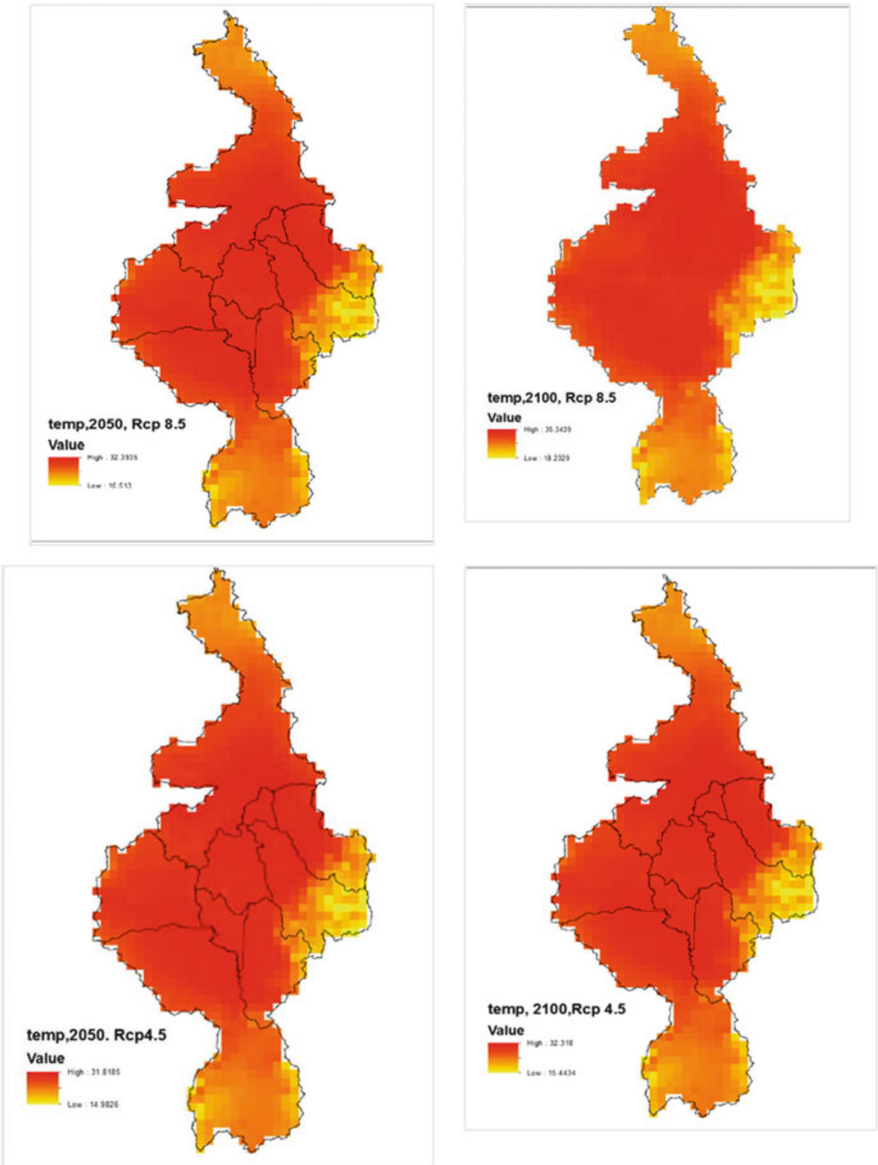

Fig. 7 The percentage of temperature changes for RCP scenarios 8.5 and 4.5 at 2050 and 2100 (Source: [9])

- Limited technologies to cope with the impacts of climate change, such as irrigation technologies that would make farmers less reliant on rain-fed agriculture.

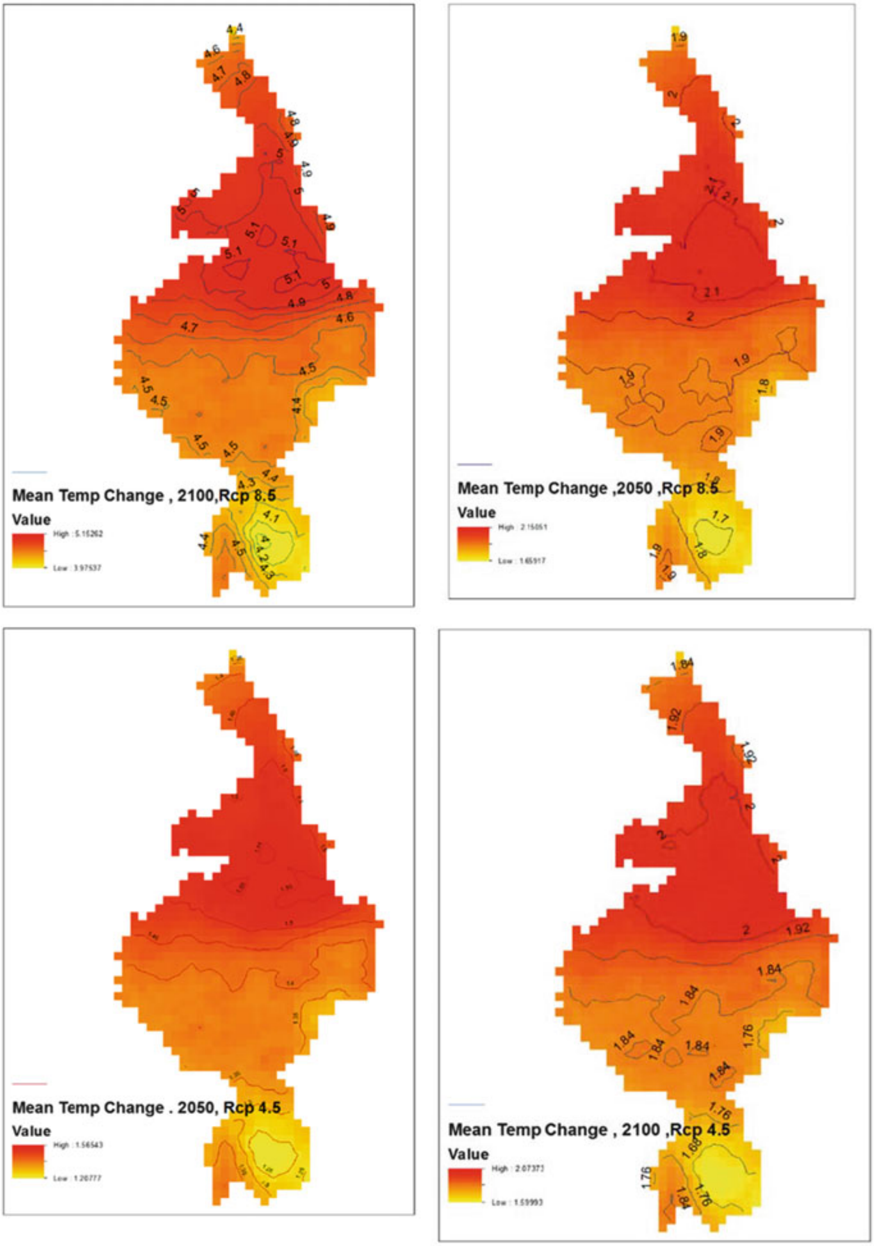

Fig. 8 Sub-basin of Nile precipitation using ensembles (40 GCMs) models RCP 4.5 and 8.5 for 2050 and 2100 (Source: [9])

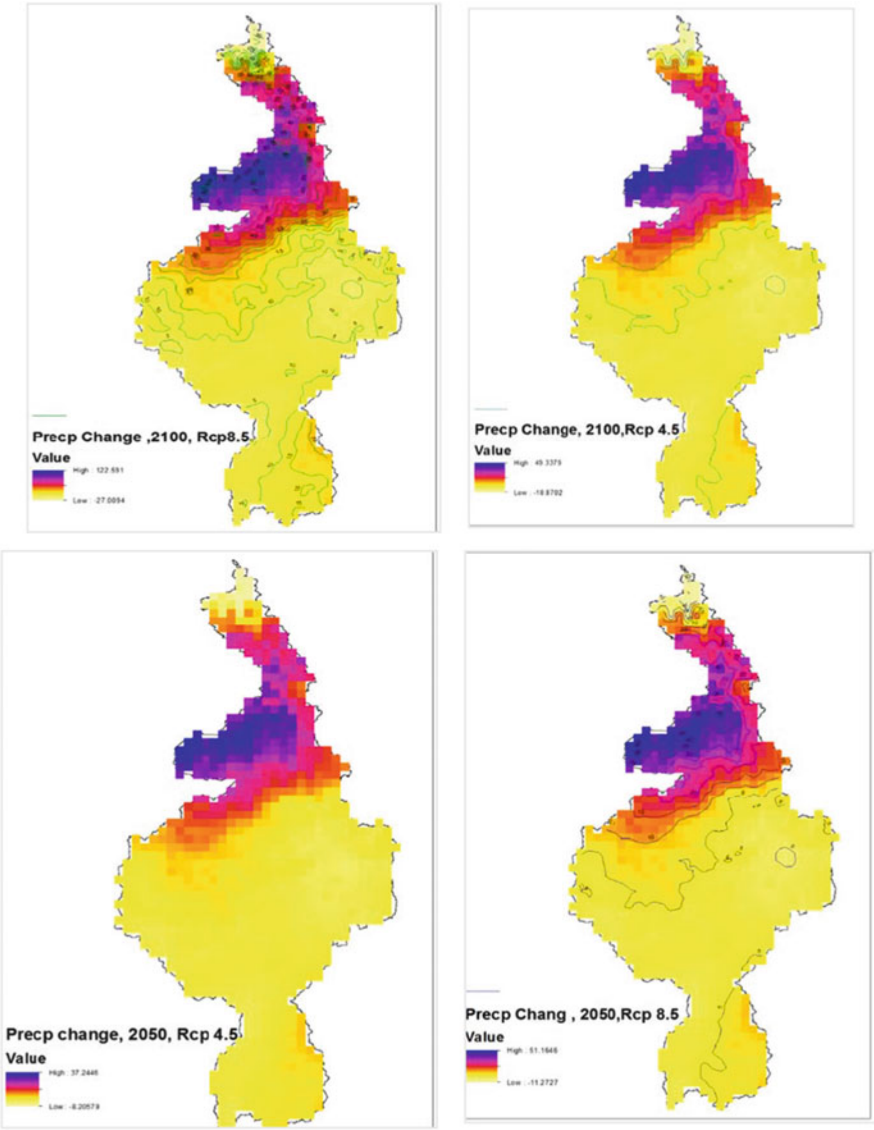

Fig. 9 The percentage of precipitation changes for scenarios 8.5 and 4.5 at 2050 and 2100 (Source: [9])

- The prevalence of dry lands which may experience reduced yields or be pushed out of production by changes in rainfall patterns or shorter growing seasons. Changes in rainfall patterns may also transform additional productive land into dry land, compounding the problem. Already water poor countries may become water stressed as weather patterns become more erratic.

Table 4 Overview of immediate and underlying consequences of climate change threats in the Nile Basin (Source: [10])

Country	Priority climate change threats by country
Burundi	Deforestation, soil erosion, degradation of river banks and lakeshores, mining, wildlife hunting
DR Congo	River and lake pollution, deforestation, soil erosion, wildlife
Egypt	Water and sea level rise, filling wetlands, desertification, water logging and soil salinity, sanitation, river bank degradation
Ethiopia	Deforestation, overgrazing, soil erosion, desertification, sanitation, loss of bio-diversity (including agro-biodiversity), floods, droughts
Kenya	River and lake pollution, deforestation, desertification, soil erosion, sedimentation, loss of wetlands, eutrophication, and water weeds
Rwanda	Deforestation, soil erosion, degradation of river banks and lakeshores, desertification, degradation of river banks and lakeshores, mining, ecosystems deterioration
Sudan	Soil erosion, desertification, pollution of water supplies, wildlife hunting, floods, droughts, sanitation, deforestation
Tanzania	Deforestation, soil degradation, desertification, river and lake pollution, poaching, and shortage of potable water
Uganda	Draining of wetlands, deforestation, soil erosion, encroachment into marginal lake-shore and riverine ecosystems, point and non-point sources pollution

- Limited capacity of governments and institutions to deal with the impacts of climate change and to strengthen resilience of the population, in particular of vulnerable groups, who are less resourced to deal with the impacts of climate change. The brain drain of qualified people further limits the ability of governments and institutions to respond to the needs of the population. Lack of access to capital, insurance cover and safety nets, in particular following disasters, and limited savings of the majority of the population that would enable them to weather crises.

As shown in Table 5, it is clear that the human dependence on the different components of the Nile Basin, particularly the grasslands have the first priority followed by activities at desert and semiarid areas as well as cropland.

3.1 Agriculture

Positive impacts of climate change could increase growth rates because of increased CO_2 concentrations and length of growing season. However, as agriculture is the largest water consumer, it will strongly be affected by variability in rainfall, temperature, and other weather conditions. As well, the impacts on rain-fed agriculture and irrigated systems are not well understood [12]. More than 80% of global agricultural land is rain-fed and, when in arid and semi-arid conditions, production will be very vulnerable to climate change [13]. In addition, although

Table 5 Human dependence on the different component of the Nile Basin (Source: [11])

Land cover in Nile Basin component(s)	Approx. area (km^2)	Population (millions)	Developed area
1. Developed/urban	32,500	30	Hydropower, domestic and industrial water supply
2. Wetlands	195,300	20	Irrigated and flood recession, arable land, livestock production, fisheries, wild plants and animals, domestic water supply, and transport
3. Forest	65,000	0.2	Wild plants and animals, domestic water supply
4. Cropland	325,500	33	Irrigated and flood recession, arable land, livestock production, fisheries, wild plants and animals, domestic water supply, transport
5. Irrigated cropland	163,000	25	Irrigated and flood recession, arable land, livestock production, fisheries, wild plants and animals, domestic water supply
6. Scrubland	130,182	2.6	Dry season pasture, wild plants and animals, domestic water supply
7. Grassland	1,366,913	27	Dry season pasture, wild plants and animals, domestic water supply
8. Desert/semiarid	976,367	7	Dry season pasture, wild plants and animals, domestic water supply
Total	3,254,555		

irrigated land represents only about 18% of global agricultural land, its yields are on average 2–3 times more than those in rain-fed areas. Thus, especially for Nile Basin food production depends both on precipitation and, increasingly, on the availability of water resources. Obviously, too little water will directly and negatively affect agriculture production. On the other hand, extreme precipitation events could lead to excessive soil moisture, soil erosion, direct damage to plants, and a delay in farm operations, all of which disrupt food production. FAO [12] categorizes climate change impacts on food production into two groups: biophysical and socio-economic (Tables 6 and 7).

Meanwhile, the economies of the NB riparian are dominated by agriculture, in terms of both Gross Domestic Product (GDP) and livelihoods. In such countries, if irrigation (1) is a dominant user of water and (2) is necessary to mitigate the seasonality and variability of rainfall, another useful indicator of scarcity (or a lack thereof) is therefore the extent of undeveloped irrigation potential. In other words, if the agricultural sector is a major user of water (usually for irrigation), then irrigation is significantly underdeveloped then scarcity is low, and vice-versa.

Not including the Sudd swamps despite high development of its irrigation potential, Sudan is not physically water scarce because use of PUWR does not exceed 60%

Table 6 Climate change impacts on food production (Source: [11])

Biophysical	Socio-economic
Physiological effects on crops, pasture, forests, livestock (quantity and quality) Changes in land, soil, water resources (quantity and quality) Increased weed and pest challenges Shifts in spatial and temporal distribution of impacts Sea level rise, changes to ocean salinity and acidity Sea temperature rise causing fish to inhabit different ranges	Decline in yields and production reduced marginal GDP from agriculture Fluctuations in world market prices changes in geographical district-button of trade regimes Increased number of people at risk of hunger and food insecurity Migration and civil unrest

Table 7 Irrigation in Nile Basin (Source: [10])

Country	Use as % of total abstractions	Potential within NB (ha)	Area already irrigated in NB (ha)	% of potential
Burundi	77%	80,000	Not known	Not known
Rwanda	68%	150,000	2,000	1%
Tanzania	89%	30,000	10,000	33%
Kenya	79%	180,000	6,000	3%
DRC	31%	10,000	0	0%
Uganda	40%	202,000	9,120	5%
Ethiopia	94%	2,22,000	23,160	1%
Eritrea	95%	150,000	15,124	10%
Sudan/1/2	97%	2,750,000	1,935,200	70%
Egypt	86%	4,420,000	3,078,000	70%

3.2 Extremes Weather Events

There is evidence that the Nile Basin has been suffering from an increase in the frequency and intensity of extreme weather events (EWEs), such as droughts and floods in recent decades, and that this trend is projected to continue [15]. Droughts have increased in frequency and intensity in East Africa, with droughts occurring in each decade over the past 50 years [14]. The 2011 drought in Eastern Africa is one of the worst Ethiopia has faced in 50 years. As is evident in Tables 8 and 9, EWEs can cause death and injuries, as well as contaminate water sources. They also lead to intense incidences of water-borne diseases, and damage property, impede movement of people and goods and communication, and disrupt the supply of essential medical and health services. Droughts can increase food insecurity and malnutrition, increase the risk of outbreaks of diseases such as meningitis, or diseases spread by contaminated food and water. Increases in EWEs associated with climate change are expected to lead to additional deaths and injuries, and population displacement, increasing the risk for infectious disease outbreaks. This is

Table 8 Number of people killed or affected by EWEs in Africa (1993:2003) (Source: EM-DAT data set quoted in Conway 2009)

Type	Killed	Affected
Flood	9,642	1,993,900
Drought/famine	4,453	110,956,000
Wind storm	11,335	5,687,000
Extremes temperatures	147	8,000
Total	15,713	136,690,000

Table 9 Health related impact of climate change (Source: [11])

	Climate change	Adverse health impact
Direct	Extreme weather events	High levels of mortality and morbidity, changes in disease prevalence and patterns, health delivery infrastructure, and access to health
	Temperatures	Thermal stress, skin cancer, eye diseases
	Air quality	Cardio-respiratory diseases, allergic disorders, asthma, airway diseases
Indirect	Temperature	Food availability, malnutrition, famine, infectious diseases of migrants and droughts
	Extremes event; rainfall, temperature, ecosystem changes	Faster spread of contagious diseases due to migration, natural resource conflict, food and water scarcity, famine, malnutrition, limited access to health services
	Precipitation	Water-borne, vector-borne, and zoonotic diseases, droughts, food and water availability
	Ecosystem composition and function	Food yields and quality, aeroallergens, vector-borne, water-borne, and zoonotic diseases

particularly the case in low-income countries with lower climate change resilience and adaptive capacities [24].

The direct and indirect impacts with their adverse effect on human health have been illustrated in Table 9.

3.3 *Sea Level Rise*

The Nile Basin is one of the regions that are most vulnerable to the impacts of sea level raise due to ocean thermal expansion and glacial melt. Projections of global mean sea level rise over the period of 1980–2099 are expected to be in the order of 0.18–0.59 m [16]. Sea level rise is expected to worsen coastal erosion and enhance salt water intrusion. Coastal erosion reached 23–30 m annually in some areas. Coastal cities of the Nile Basin countries are expected to be particularly affected by climate change and sea level rise due to its relatively low elevation at its Mediterranean shoreline in Egypt. A one-meter sea level rise may possibly submerge Alexandria (Elsharkawy et al. 2009 in [17]). Nile Basin cities that are at risk due to sea level rise are Alexandria and Dar es Salam, United public of Tanzania.

A sea level rise of 0.43 m will result in the flooding of coastline inhabitants by 2100, while another millions people will be forced to migrate during the period 2000–2100. The cost of damage to infrastructure over the century is projected to US $38 billion [18] over all of Africa. However, with adaptation, the projected impacts could be significantly reduced. For people-based impacts due to flooding and forced migration, the most vulnerable countries are Egypt and the United Republic of Tanzania, while for economic damages, Egypt is the most vulnerable [18]. Thus, in order to safeguard human health and other socio-economic benefits an Integrated Coastal Zone Management (ICZM) and Marine Protected Areas (MPAs) plan should be considered in strategic goals for these countries. Due to socio-economic factors regarding climate change, 2070s exposed assets for Alexandria, Egypt, and Dar es Salam United public of Tanzania the most and they may experience losses more than 528.2, 5.2 US$, respectively [19].

3.4 Water Scarcity, Droughts, and Withdrawals

For the purpose of this report water scarcity is defined as inadequacy to meet demand, while drought is defined as a negative, climatic aberration from expected conditions. It is important to make this distinction as scarcity can be mitigated proactively by catchment protection, demand management, storage (trans-seasonal or trans-annual), and strategic water allocation. Drought is something that is beyond human control, although it can be mitigated both on a prophylactic basis by the provision of storage facilities, for instance, or reactively, however, ideally there should be pre-existing response plans.

A helpful overall indicator of water scarcity, which has both spatial and temporal characteristics, is the length of growing season at a particular location. Figure 10, which does not differentiate between irrigated and rainy growing seasons, clearly suggests a prevailing lack of scarcity in the far South, with scarcity increasing rapidly with latitude such that most of the Eastern Nile Region is completely water scarce with the exception of the Egyptian Nile where scarcity is in any case mitigated by the Aswan dam. As mentioned above, however, given adequate economic resources, scarcity can be mitigated by investments in water management infrastructure.

It is reasonable to conclude that given adequate economic resources, and sound technical approaches to demand management and to the allocation and management of water in the Nile Basin, that with the exception of Egypt, physical water scarcity is not an issue – at least not at the basin level or national levels. This does not mean, however, that as one approaches the point of use that localized scarcity is not an issue.

Even where water would seem to be plentiful in relation to the demands, drought events compromise the availability of water and are widely reported throughout the basin where records of droughts go back to biblical times. Drought results from phenomena such as El Niño and possibility others. Such influences explain normal long-term drought events. But such events have begun to increase in intensity and

Fig. 10 Length of growing season in the Nile Basin (Source: [15])

frequency throughout where their effects are worsened by population growth and catchments degradation. Increases in intensity and frequency are thought to arise from atmospheric pollution, global warming, and associated climate change and are manifested either by increasingly intense rainfall events or by increasing variability in rainfall. For instance, since 1997, Uganda has endured two El Nino related drought cycles and between the 30-year periods from 1970 to 2000; there has been twice as many droughts as there were in the 50-year period from 1920 to 1970. In addition, droughts can be seasonal or long-term and the country recently suffered from a prolonged drought that has caused water shortages across the country leading even to water level drops in various water sources, including Lake Victoria. This situation changed dramatically in recent days when some 400,000 people were affected by the catastrophic floods covering a band running east-west from Ethiopia to Senegal. Similarly, Rwanda is increasingly experiencing long periods of drought which tend to become cyclical and persistent, particularly in the East and South West, while in Burundi, decreasing spring flows are thought to result from ongoing changes in rainfall [20].

Despite these cases in the Nile Equatorial Region, droughts are reportedly more likely and more severe in the Eastern Nile region which is characterized by highly variable climate and river flows, making it prone to consequences of extremes of droughts and floods even in areas such as the Ethiopian and Eritrean highlands where "normal" rainfall is associated with long growing seasons and usually high biomass (Fig. 11). Although the degrees of the effects of drought have always

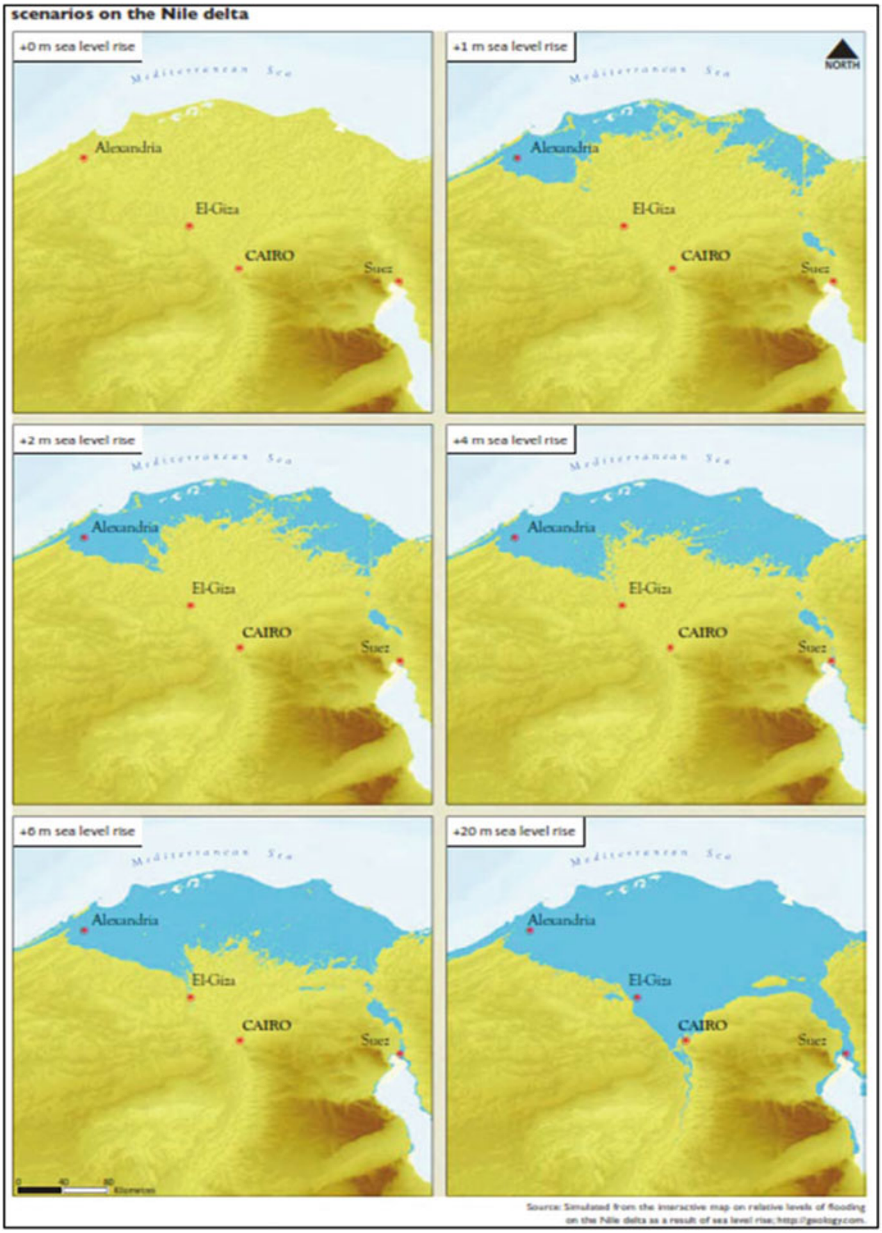

Fig. 11 Scenarios showing the impacts of different see level rise (0, +1, +2, +4, +6, and +20 m) on the Nile Delta (Source: [21])

varied from year to year (drought has been a recorded phenomenon in Ethiopia since 250 BC); the past three decades have seen recurrent droughts to become more severe and affect the lives of millions of Ethiopians every year. Despite the increased risks associated with the Eastern Nile countries, throughout the Nile Basin as a whole, drought is often claimed to be the most significant threat to the rural poor whereby their response to a given drought both increases the effects of the next event while reducing their ability to mitigate. This is because catchment deterioration caused by deforestation (as a drought response – people affected by drought in one location are known to open up new, virgin locations) reduces the ability of the natural system to attenuate rainfall events and thereby mitigate drought.

Total water withdrawal, the following table, which has been taken from Water Report No. 29, NBI indicates water withdrawals by sector by country. It is necessary to make clear definitions used for withdrawals of water. Water withdrawal for agriculture is defined as "the annual quantity of water withdrawn for irrigated agriculture." It includes irrigation and livestock watering such as domestic and industrial water withdrawals it includes conveyance losses, consumptive losses, and return flow. It does not include water to be reserved for uses with a low consumption rate, such as navigation, recreation, mining, and cooling of power plants. It also does not include water used for rain-fed agriculture, natural vegetation, forests, or any other green cover.

Water withdrawal for domestic/municipal use is defined as "the annual quantity of water withdrawn for domestic/municipal purposes. It is usually computed as the total amount of water withdrawn by the public distribution network. It can include withdrawal by any industries connected to the network." Water withdrawal for industry usually refers to "self-supplied industries not connected to any distribution network."

Accordingly to the previous challenges in Nile Basin, each countries in the basin has addressed the suitable water policy to minimize the facing challenges and maximize the benefit for the available water resources in different scales and with integrated manner, as described in the next section.

4 The Nile Basin Opportunities

The overwhelming majority of the basin's population lives in rural areas and depends directly on the land and water resources of the basin for food, shelter, income, and energy, and thus should be conserved to enhance the livelihood in case of adapting and mitigating climate change and extremes events. Meeting these opportunity needs will require:

Planning new investments capacity for Nile Basin countries in order to predict impacts of climate change on water resources which may help accelerate planning and investment decisions in new water resources development schemes and increasing storage and demand-side management options.

Maintenance and major rehabilitation of existing systems has largely been neglected, including aspects of water infrastructure maintenance (dam safety, drainage systems and channel maintenance, levee rehabilitation, etc.) that should undergo revitalization through the reassessment of design procedures (such as the "probable maximum precipitation" and "probable maximum flood"), safety levels, and safety and monitoring programs. This is an opportunity to strengthen infrastructure and public safety beyond the uncertainties of climate change.

Operation and regulation of existing systems for optimal use and accommodating new purposes should be implemented. This means that the added complexity of climate variability and change offers a number of opportunities to reassess and optimize the operation and regulation of water infrastructure. This could include the requirements for minimum environmental flows and other ecological requirements related to water quality, seasonality of flow, vulnerability of upstream and downstream communities to rapidly changing flow rates, as well as the transboundary arrangements for water sharing.

New efficient technologies should be introduced, in case of expected changes in water availability, this may boost the development and application of innovative and efficient technologies for water resources development (e.g., desalination and reuse) as well as water resources conservation (wastewater treatment systems, irrigation efficiency improvements ("more crop per drop"). Such new schemes, however, require thorough testing to establish their respective merits and demerits and to minimize the risk of conflicting objectives in the areas of climate change adaptation and mitigation.

Moreover, cooperation between riparian countries in the Nile Basin should create a database to assess common regional policies and strategies for developments. These polices could be achieved through implementations of integrated and sustainable development plans. Consequently; these shared plans will have a great socio-economic and environment impacts on population "and citizen" needs.

The author's opinion is that integrated water resources management based on the collaborations basin-wide could be considered as an adaptation tool for climate change. As well, renewables sources of energy and power trading between riparian countries may provide some solutions for mitigation.

The Nile Basin initiative would be a suitable mechanism to achieve the cooperation between Nile Basin countries. Recognizing the need for mutual cooperative management of the common Nile Basin water resources, the Nile riparian countries have established a partnership known as the Nile Basin Initiative (NBI). The NBI is guided by the shared vision to "achieve sustainable socioeconomic development through the equitable utilization of, and benefit from, the common Nile Basin water resources." Right from inception, the Nile Basin cooperation has pursued participatory approach to the Strategic Action Program to translate this shared vision into activities and projects. The NBI Strategic Action Program is implemented through two complementary programs: a basin-wide Shared Vision Program (SVP) and Subsidiary Action Program (SAP) at sub-basin level. The basin-wide projects under the Shared Vision Program are aimed at building confidence and capacity across the riparian countries and establishing the necessary analytic tools and information systems for future joint management of the Nile Basin water resources. Cooperative investment and action projects are being implemented under the two sub-regional Subsidiary Action Programs. Currently, the Nile Basin countries are close to concluding an agreement on legal and institutional framework for the cooperative development and management of the shared water resources. This will promote equitable utilization of the shared resources on a win-win and sustainable bases.

5 Vulnerability and Adaptation Capacity

Adaptation to present climate variability and extreme events forms the basis for reducing vulnerability to future climate change. An adaptation strategy has to be developed within the context of the country or region in which it is to be implemented. Adaptation happens at various levels within the society: national, regional, local, community, and individual. The adaptation process is important in optimizing available resources across sectors and engaging the broadest possible group of stakeholders.

Like any other River basin in Africa, the ultimate regional impacts of climate change in the Nile Basin are linked to the levels of vulnerability and the adaptive capacity of the individual states and the basin as a whole. This means that any effective solutions need to increase the extent of adaptation significantly in order to reduce vulnerability at household, national, and regional levels.

Uncertainty over rainfall levels will create significant challenges for managing water and sanitation. Demands on water supplies will increase, while replenishment will be less predictable, requiring dedicated water conservation, leak reduction, and education programs. This is exemplified in Tables 10 and 11.

The climate change impacts on land and water management in the Nile Basin revolve around water flows, availability, and use for domestic and industrial purpose, as well as agriculture (including inland fisheries and activities in forest areas). Agriculture is by far the main water user. Households engaged in agriculture are the primary group influenced by climate change and these need to be targeted to

Table 10 Total water withdrawals (Source: [22])

	Year	Volume	% of total	Volume	% of total	Volume	% of total	Volume	% of total
Burundi	2000	222	77%	49	17%	17	6%	288	0.25%
Rwanda	2000	102	68%	36	24%	12	8%	150	0.13%
Tanzania	2002	4,632	89%	527	10%	25	0%	5,184	4.44%
Kenya	2003	2,165	79%	470	17%	100	4%	2,735	2.34%
Uganda	2002	120	40%	134	45%	46	15%	300	0.26%
DRC	2000	112	31%	186	52%	58	16%	356	0.30%
Ethiopia	2002	5,204	95%	333	6%	21	0%	5,558	4.76%
Eritrea	2004	550	95%	31	5%	1	0%	582	0.50%
Sudan	2000	36,069	97%	987	3%	258	1%	37,314	31.95%
Egypt	2000	59,000	92%	5,300	8%	4	0%	64,304	55.07%
Total								116,771	

Table 11 Regional impacts of climate change versus vulnerability and adaptive capacity

Regional impacts of climate change	Vulnerability and adaptive capacity
• Increase in droughts, floods frequency of some extreme events (alternating floods and droughts) in some places, and other extreme events would add to stress on water resources, food security, human health, and infrastructure, constraining development	• Adaptive capacity is low due to low GDP per capita, widespread poverty (the number of poor grew over the 1990s), inequitable land distribution, and low education levels. There is also an absence of social safety nets, in particular after harvest failures
• Changes in rainfall and intensified land use would exacerbate the desertification process (namely in Western Sahel and Northern Africa)	• Individual coping strategies for desertification are already strained, leading to deepening poverty. Dependence on rain-fed agriculture is high
• Grain yields are projected to decrease, diminishing food security, and particularly small food-importing countries	• Climate change has to be recognized as a major concern with respect to food security, water resources, natural resources productivity and biodiversity, human health, desertification, and coastal zones
• Sea level rise would affect coastal settlements, flooding and coastal erosion, especially along the eastern Southern African coast as well as in the Mediterranean	More than one quarter of the population lives within 100 km of the coast and most of Africa's largest cities are along coasts vulnerable to sea level rise, coastal erosion, and extreme events
• Major rivers (including the Nile and its tributaries) are highly sensitive to climate variations and may experience decreases in run-off and water availability, affecting agriculture and hydropower systems, which may increase cross-boundary tensions	• Adaptive capacity will depend on the degree of civil order, political openness, and sound economic management

implement adaptation measures. At the same time, agriculture greatly affects water catchments [23].

6 Conclusions

The following are the main conclusions that should be taken into consideration as early as possible to adapt and mitigate with climate changes:

- Proactively preparing for climate change can reduce impacts while also facilitating a more rapid and efficient response to changes as they happen. Such efforts are beginning at different nations in Nile Basin to build adaptive capacity and resilience to climate change impacts.
- Reducing non-climate-related stresses that contribute to existing vulnerabilities can also be an effective approach to climate change adaptation.

- Increasing resilience and enhancing adaptive capacity provide in most of the Nile Basin. Regions, water resources managers, and planners will encounter new risks, vulnerabilities, and opportunities that may not be properly managed within existing practices.
- Climate change impacts, many institutional, scientific, economic, and political barriers present challenges to implementing adaptive strategies.
- Climate change could have very serious impacts on growth and development. The costs of stabilizing the climate are significant but manageable; delay would be dangerous and much more costly.
- Action on climate change is required across all Nile Basin countries, and it need not cap the aspirations for growth of rich or poor countries.
- A range of options exists to cut emissions; strong, deliberate policy action is required to motivate their take-up.
- Climate change demands an international response, based on a shared understanding of long-term goals and an agreement on frameworks for action.
- The basin is also prone to sever inter- and intra-annual variability of rainfall. The basin's population is expected to double every 25 years. High population growth and increased variability of rainfall is forcing many of the countries, which depend on rain-fed agriculture, into irrigated farming system thus increasing overall consumptive water demand on the system. Indications are that cooperative development of the basin's water resources would lead to more efficient and sustainable development of the basin's water sources. A regional system to apply an integrated water resources management in Nile Basin countries' water policies is required.
- A shared knowledge base, analytical capacity, and supporting stakeholder interaction, for cooperative planning and management decision making for the Nile River Basin management of the shared Nile water resources is needed.
- Mainstream sustainable management of natural resources into national economic and sustainable development policies.

References

1. IPCC (1996) Climate change 1995: impacts, adaptations and mitigation of climate change: scientific-technical analyses. Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press
2. IPCC (2007) Climate change 2007: Synthesis Report. Fourth Assessment Report (AR4). An assessment of the Intergovernmental Panel on Climate Change (IPCC), Geneva
3. Conway G (2009) The science of climate change in Africa: impacts and adaptation, Discussion paper no 1. Grantham Institute For Climate Change, Imperial College, London
4. Sayed MA, Nour M (2006) Impacts of climate change on Nile flows. Eastern Nile Technical Regional Office (ENTRO), Addis Ababa, 19p
5. Elshamy ME, Seierstad IA, Sorteberg A (2011) Impacts of climate change on Blue Nile flows using bias-corrected GCM scenarios. Hydrol Earth Syst Sci 13:551–565
6. Elshamy ME, Wheater HS, Gedney N, Huntingford C (2009) Evaluation of the rainfall component of a weather generator for climate impact studies. J Hydrol 326:1–24

7. Mohamed Y, Hurk BVD, Savenije H (2005) Hydro climatology of the Nile: results from a regional climate model. Hydrol Earth Syst Sci Discuss 2:319
8. Mohamed Y, Savenije H, Bastiaanssen W (2005) New lessons on the Sudd hydrology learned from remote sensing and climate modeling. Hydrol Earth Syst Sci Discuss 2:1503
9. CERAL, Climate and Environment Risk Assessments Laboratory, Climate Change Research Institute (ECRI), National Water Research Center (NWRC). Ministry of Water Resources and Irrigation, Egypt (2016) Assessing for climate change in Nile Basin using ensembles of 40 GCMs Models
10. NBI (2005) Nile Basin initiative: shared vision program, project appraisal document for the water resources and management project. World Bank Report No. 31989, April 2005
11. Africa Environment outlook 2 (AEO2), AMCEN/UNEP in collaboration with, Agency International pour le Development de information Environmental (ADIE) http://www.adie-prgie.net, National Environmental Management, Authority (NEMA) http://www.nemaug.org , Centre for Environment and Development for the Arab Region & Europe (CEDARE) http://www.cedare.org.eg, Network for Environment and Sustainable Development in Africa (NESDA) http://www.nesda.kabissa.org
12. Food and Agriculture Organization FAO (2006) Working Paper No. 32 Water for Rural Development, Molden, Amarasinghe and Hussain, IWMI, 2001 .Land and water bulletin No. 4 irrigation potential in Africa—a basin approach
13. Bates, B., Kundzewicz, Z., Wu, S., J. Palutikof (2008) Climate change and water. Technical paper of the Intergovernmental Panel on Climate Change. IPCC Secretariat, Geneva
14. AMCEN (2011) Addressing climate change challenges in Africa: a practical guide towards sustainable development. African Ministerial Conference on Environment (AMCEN), Addis Ababa
15. Boko M, Niang I, Nyong A, Vogel C, Githeko A, Medany M, Osman-Elasha B, Tabo R, Yanda P (2007) Africa climate change 2007: impacts, adaptation and vulnerability. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (eds) Contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, pp 433–467
16. Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt K.B., Tignor M., H.L. Miller (Eds.) (2007) Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007. Cambridge University Press, Cambridge/New York
17. Elsharkawy HE, Rashed H, Rached IF (2009) Climate change: the impacts of sea level rise on Egypt 45th ISOCARP Congress 2009. International Society of City and Regional Planners (ISOCARP), The Hague. http://www.isocarp.net/data/case_studies/1456.pdf
18. Brown S, Kebede AS, Nicholls RJ (2011) Sea level rise and impacts in Africa, 2000 to 2100. University of Southampton, Southampton
19. Nicholls RJ Hanson S Herweijer C Patmore N Hallegatte S Corfee-Morlot J Chateau J Muir-Wood R (2008) Ranking port cities with high exposure and vulnerability to climate extremes: exposure estimates. OECD Environment Working Papers, No. 1, OECD publishing, doi:10.1787/011766488208
20. Hydrophil, Consulting & Knowledge Development GmbH, In Associations with ETDA & CEDARE (2008) Inception Report/Annex A Situation Assessment Report Needs Assessment and Conceptual Design of the Nile Basin Decision Support System Consultancy (NBDSS)
21. Africa Environment outlook 3 (AEO3), AMCEN/UNEP in collaboration with, Agency International pour le Development de information Environmental (ADIE) http://www.adie-prgie.net , National Environmental Management, Authority (NEMA) http://www.nemaug.org , Centre for Environment and Development for the Arab Region & Europe (CEDARE) http://www.cedare.org.eg, Network for Environment and Sustainable Development in Africa (NESDA) http://www.nesda.kabissa.org

22. Mohamed Y, Bastiaanssen W, Savenije H (2004) Spatial variability of evaporation and moisture storage in the swamps of the upper Nile studied by remote sensing techniques. J Hydrol (Amsterdam) 289(1/4):145
23. Zahran S, Nour El Dien M (2010) Vulnerability of Nile River to climate change and human activities, (DSS application at Nile River). Degree of Doctor of Philosophy in Civil Engineering, Ain Shams University
24. Confalonieri U, Menne B, Akhtar R, Ebi KL, Hauengue M, Kovats RS, Revich B, Woodward A (2007) Human health. Climate change 2007: impacts, adaptation and vulnerability. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (eds) Contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, pp 391–431
25. IPCC (2014) Climate change (2014). The physical basis of climate change: contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge
26. IPCC (2014) Climate change (2014). Impacts, adaptations and vulnerability: scientific-technical analyses: contribution of working group ii to the second assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge
27. Mohamed DY (2003) Nile Basin cooperation: a review of the literature. Curr Afr Issues 26
28. WHO (2005) Air quality guidelines; global update 2005. World Health Organization. Available: http://www.who.int/phe/health_topics/outdoorair_aqg/en/. Accessed 21 July 2011

Part VI
Hydropolitics and Legal Aspects

The Hydropolitics of the Nile River Basin

Mohamed Salman Tayie

Abstract The history of water relations in the Nile River basin indicates the existence of cooperation as well as conflict since the 1950s. Recently, there has been negative escalation of disputes regarding the hydropolitical interactions within the regional system of the Nile Basin region; reaching a critical level after the failure of negotiations of the Framework Convention for the Nile Basin (Entebbe). The situation grew further strained after Ethiopia embarked on the construction of the renaissance dam without prior notification to downstream Egypt and Sudan.

This study aims to analyze the hydropolitical interactions in the Nile Basin with a focus on conflictual interactions. This study is based on the hydropolitical framework, which means the analysis and interpretation of international political phenomena, both conflictual or cooperative, in the context of water issues in the Nile Basin. This framework is related to some analytical concepts such as: Hydrostrategic, Hydro-Hegemony, hydropolitical flexibility.

The study analyzes three issues: (1) the dimensions of the water conflict in the Nile Basin, with a focus on the contradictory attitudes of the countries upstream and downstream; with a focus on the Ethiopian Hydropolitical behavior towards the Renaissance Dam; (2) the role of the external factors in regional and international actions in the Nile Basin; and (3) the potential scenarios of the hydropolitics (conflict and cooperation) in the Nile Basin.

Keywords Ethiopian Renaissance Dam, Externality, Hydro-hegemony, Hydropolitics, Selling water, Water conflict, Water diplomacy, Water sharing

M.S. Tayie (✉)
Faculty of Economics and Political Science, Cairo University, Giza, Egypt
e-mail: msalman@feps.edu.eg

A.M. Negm (ed.), *The Nile River*,
Hdb Env Chem (2017) 56: 599–654, DOI 10.1007/698_2016_106,

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1 Introduction

The history of water relations in the Nile River basin area indicates the existence of relationships of both the cooperation and conflict since the 1950s [1].

Recently there has been a negative escalation of disputes regarding the hydro-political interactions (water politics) within the regional system of the Nile Basin region; reaching a critical level.

Upstream Nile Basin states have chosen to adopt extreme views; escalating the level of dispute. This was clear before, during, and after the negotiations over the Framework Agreement of the Nile Basin which started with the negotiating committees then meetings of the Nile water ministers; initiating with the Addis Ababa meeting in January 2006 till the meeting in Sharm El sheikh in April 2010.

On the 14th of May, 2010, five of the upstream states individually signed the Entebbe Framework Agreement to establish the Nile Basin Commission regardless of the objections expressed by the downstream states (Sudan enjoys a unique situation since it possesses the main three characteristics of a riverine state, it is an upstream states in the North, and waterway stream in the North and Middle and an upstream state in the Ghazal sea area which receive approximately 540 billion cubic meter of rain. For more details, see Egypt and Sudan [2]) after the failure of the negotiations over the Nile Basin Framework Agreements which lasted for approximately 5 years (2006–2010). Then, Burundi made an escalating step by signing the Agreement in February 2011 complementing the quorum by being the sixth state to the Agreement.

The tension of the situation was increased after the separation of South Sudan on the 9th of July, 2011. This was the event that added more negativity to the developments of the hydropolitical transaction (water politics) in the Nile Basin and doubled the political congestion in the region, especially in the light of the Juba statements on 22 March 2013 which intensified the geostrategic and political siege on Egypt.

In parallel, there were conflictual interactions on the Nile issues caused by the increased Ethiopian planning to execute a number of new dams on the Nile upstream in the last decade. Then, Ethiopia exploited the internal disturbances and instability in Egypt during the 25th revolution and declared – individually – in February 2011 that it plans to build the "Grand Ethiopian Renaissance Dam" with technical specifications that constitute a threat to the Egyptian water security. Ethiopia established the milestone of the renaissance dam on the 2nd of April, 2011, starting a new era of water conflicts with Egypt [3].

The current developments in the Nile Basin region stimulated a need to analyze the hydropolitical scene, especially analyzing the "Ethiopian Renaissance Dam" and the dams which are planned to be built in the future, especially those that will, consequently, affect the Egyptian share of the river water which is one of the most important dimensions of Egyptian water security, in addition to the resulting political and legal problematic issues related to the obligations, Ethiopia should respect rules concerning "prior notification" when executing those water projects regardless of one of the customary international laws which states "not to cause harm" to other states.

The aforementioned developments contributed to aggravation of the situation in the Nile Basin stimulating a number of fears among the Egyptian society especially in the light of using the term "Water War" which was repeatedly declared by the late Ethiopian Prime Minister Meles Zenawi. Those statements caused a lot of controversy and confusion in the legal, political, hydraulic, engineering and media domains [4].

The gradual decreasing of the individual water shares doubled the echoing of such statements in the Egyptian society. The current quota is less than 700 cubic meter per person/year. According to the international standards, this rate is equal to the "water poverty line" of a state. As for the quality of the water, data signifies that there is a rapid decrease in the surface and underground water [5].

Generally, the current developments in the Nile Basin impose a critical situation on Egypt and on its water security [6].

The concept of "Egyptian Water Security" – as one of the Egyptian national security factors – is connected to economic, social, political, and military aspects because water became the center of strategic conflicts which should be avoided via the investment of all human, financial, and natural capabilities (for more details about the concept and indicators of the Egyptian water security, see [7]).

1.1 The Objective of the Study

The objective of the study is to analyze the hydropolitical interaction of the Nile Basin through the following analytical axes:

- The hydropolitical framework.
- Water conflicts in the Nile Basin.
- The role of the regional and international factors in the Nile Basin.
- The scenarios of the hydropolitics in the Nile Basin.

2 The Hydropolitical Framework

The term framework refers to the analysis of hydropolitics. This framework is to analyze the interdisciplinary studies, where the international conflicting or cooperative political phenomena is analyzed, in the light of the constants and water rights.

The hydropolitical approach came into light as a result of the intense impact of the water issues on the international relations among the onshore states located in the Basin of a single river. The definition of the term exposes the extent of connectivity between the political and water phenomena. It also clarifies that the water phenomenon has major political dimensions and consequences that cannot be ignored through either scientific analysis or practical water policies, especially on the level of the internal water relations among states.

There was an increase of interest in the hydropolitical approach as a result of the growing concern regarding the water issues on the political level. The "water" notion is presented in the framework of a network of international cooperation or confrontation around the water sources.

Consequently, the water issues were politicized, especially that they are one of the main causes of the international conflicts. In this context, many terms were born such as: "water conflicts," "water wars," "water crisis," and "water security" [8].

The hydropolitical approach is not a modern term. John Waterbury, a political scientist, is the first who used the term in 1979. He stated that the term shows the extent to which the political and water phenomena are connected. He asserted that the water phenomenon has very important political implications and consequences dimensions, especially in the level of the water policies among states. He applied this concept of the water interactions to the Nile Basin [9], whereas Molinga preferred to use the term as: "a section from the water policy which has been well studied and analyzed because it is a very general phenomenon with a geopolitical importance. It is also an interesting issue in the domain of international relations" [10].

The approach is also used to analyze issues related to the assignment of water among the upstream and downstream regions, as well as analyzing the issue of transporting the water amongst the Basins located in different regions within a single state. Consequently, the objective of the approach is to understand and analyze the interactions of the water cooperation and conflict and the way to negotiate concerning them [11].

The hydropolitical framework is also concerned with recognizing the governing rules that are employed to assign water to establish a water rights system via the distribution of water among the states. In addition, it is concerned with the development of different analytical methods which assist in the evaluation of the different choices of water resources uses which – in turn – attempt to define the potential negative consequences if no agreement is reached regarding the common uses of the water sources [12].

In the middle of the 1970s, Aaron Wolf implemented the approach as an analytical concept regarding the hydropolitical interaction in the Jordon River basin in an attempt to analyze and explain it [13]. In 1995, Ohlsson wrote a book that included many studies which were analyzed by the hydropolitical approach [14].

In 2002, Allan used the term hydropolitics as an analytical concept to analyze and explain the hydropolitical relations in international river basins located in the Middle East [15].

Meissner presented a definition of the term which reads: "investigation and analysis of structured interactions among states and non-state actors and a wide range of participants, such as individuals within and outside the state with respect to the authoritarian distribution or the use of the international and national sources of water, and therefore these interactions include the kind of sovereignty over the water" [16].

As a result of the expansion of the meaning of security to encompass new aspects, including water security, the concept of "hydropolitical security dilemma" emerged to indicate that states are increasingly considering water as a national security issue [17].

Three regions in the Middle East suffered from this dilemma; the Nile Basin, the Jordan River basin, and the Basin of Tigris and Euphrates. Consequently, the decrease of water is a matter of national security for the Middle East states [18].

This concept can be beneficial to the dynamics of the international relations in the regions in which water rarity can be a cause to trigger a conflict [19].

Anthony Turton argued that hydropolitical studies are a relatively new academic approach. As is the case with any other approach, there is enormous ambiguity regarding the aspects and definitions related to it, which are drafted randomly.

The hydropolitics framework is linked to many concepts which form a large network; the most important concepts are as follows.

2.1 The Concept of Hydro-strategic

It is an analytical concept depending on studying and explaining the strategic phenomena in the light of the hydrological facts. This concept asserts the overlapping of the hydrological phenomenon with the strategic issues. It also reveals that the water concept has many dimensions in addition to the technical-engineering realm, the most importance of which are the political and strategic dimensions as well as the economic, environmental, geographic, and legal ones. Wolf was the first to use the term as an analytical concept to explain the strategic and political interactions related to the water variables in the Jordon River basin [20].

2.2 The Concept of Hydropolitical Flexibility

It is defined as: "the experiences and resources that organizations need to adopt in order to change the environmental and social terms related to fresh waters." Consequently, it is linked to the ability of the system to adopt the notion of "change" to establish cooperation in regard to water [21].

2.3 The Concept of Hydropolitical Weakness

It is defined as: "the risks relating to the political disputes around the mutual water systems." The relationship between the institutions, the change and the hydro-political weakness is illustrated in the growing possibility of conflicts which may erupt when the change rate within the Basin exceeds the ability of the institutions to cope with such change [22].

2.4 The Concept of Hydro-hegemony

This concept refers to "the conflict of departments, political and geo-strategic interests between upstream and downstream states, where the upstream states use the water to get more power, while the downstream states use power to get more water" [23].

Hegemony can provide order and stability to ensure water flow to the major states, and on the other side, the hegemony may be accompanied by exorbitant costs for the weaker states in the political equation, resulting in the lack of control on the organization and management of the river decisions and absence of appropriate allocation of water for those states. This may cause political unrest, opening the door for severe water conflicts. It is noticeable that the hydro-hegemony is the most prevalent in the Middle East rivers basins (for more details about the concept of hegemony and the conversion of hydropolitical to the hegemony of hydro-hegemony, see [24]).

3 Water Conflicts in the Nile Basin

The essential substance of the international water conflict is "water." Water can be a subject of disturbances, uprisings, disputes, and conflicts among the states located on the banks of a certain international river especially in the absence of an agreement amongst such states regarding the legal and regulatory rules governing the waters of the river.

In consideration of the regional water system of the Nile, it is clear that it embodies this principle clearly, since the dimensions and the domains of international conflicts over the water can be illustrated in three main domains:

First: The conflict over the extent of "legality" of the former agreements which were signed during the end of the nineteenth century and the first half of the twentieth century, in addition to how they can be considered as a legal reference to regulate the issues of fair and just uses of the river waters.

Second: The conflicts over the allocations of the mutual waters in the Nile Basin, and the best rules governing the fair and just use.

Third: The conflicts over the prior notification condition when executing water projects by the upstream states [25].

3.1 The Conflict over the "Legality" of the Historic Agreements

It is considered one of the domains of the international water conflicts in the regional system of the Nile.

The upstream states stress the "illegality" of the former Agreements because they were not parties to them since they were under occupation during the ratification of the Agreements. On the other hand, Egypt and Sudan insist to adhere to the two principles of "the international inheritance of the Agreements" and "the acquired historical right" [26].

3.1.1 The Stands of the Nile Upstream States from the Historic Agreements of the Nile

The upstream states refuse all the former Agreements on the Nile and do not recognize any of them. They want those Agreements to be cancelled and replaced by a new Agreement (for more details on the positions of these countries of the Nile water agreements, see [27]).

Since the independence of the Nile Basin states, there are increasing demands from those governments to reconsider those old Agreements claiming that the former governments did not sign them, but they were signed by the occupying states on their behalf. The Nile upstream states – especially Ethiopia, Tanzania, Kenya, and Uganda – always demand to amend the Nile water Agreements, especially the Agreements of 1929 and 1959 (for more details, see [28]).

Those states list a set of reasons for their refusal of the Agreements, including [29]:

- Those agreements were signed during the occupation period, therefore the Basin states did not have full sovereignty in the time of signature.
- The Nile waters agreements – in general – were on the side of Britain (Egypt's side later).
- Thanks to those agreements Egypt achieved the right to supervise and act freely in regard to the water of the Nile on the account of the other states in the Basin.

Ethiopia declared its absolute refusal to all the historical agreements regarding the Nile waters because of some concepts that were rooted in the Ethiopian minds concerning the powers their emperors enjoyed [30]. For centuries there were legends about the ability of the Habasha emperors to stop the flowing of the Nile waters into Egypt. In the middle ages, there was a rising belief among the Ethiopian Emperors of their ability to divert the Nile's watercourse, something that negatively impacted the hydropolitical relations between Egypt and Ethiopia [31].

In this context, the historical books mention that the Habesha governors always used the Nile water issue to place pressure on Egypt, especially in connection with the way Egypt treats its Christian citizens.

In the era of King "David Ben Josef" of Habesha (1381–1411), he did not only threaten to divert the waterway of the Blue Nile, but also attacked the Egyptian borders. His troops reached Aswan exploiting the unrest that Egypt suffered from under Sultan "Barqouq Elmamluky" [32].

Some historical documents show that the Habesha king in the first period of the eighteenth century sent a threatening letter to the Ottoman ruler of Egypt which reads:

> only in the Nile lies your punishment because the Lord has the upstream and the flood of this river under our disposal and we can use the water of it in the way that can damage you extremely [33].

Hurst mentioned misleading reports speaking about the diversion of the Blue Nile waterway to flow into the Red Sea, transforming Egypt into a harsh desert, he said:

> This nonsense is a remainder of the notion which prevailed in the middle ages when Egypt had a famine. The Egyptians imagined that the Hebasha has converted the direction of the Blue Nile. The ruler of Egypt sent an ambassador to the king of Habasha with piles of presents asking to put the Nile on the right course. That was a real nonsense since the conversion of the Blue Nile requires works similar to the works needed to convert the Rhine River to the Adriatic sea across the Alps [34].

Yet, it can be said that the unrest in the foreign policies between Egypt and Ethiopia regarding the water of the Nile goes back to the 1950s. The strong relations between Ethiopia and the USA – at that time – influenced the Ethiopian–Egyptian relations negatively during the administration of Nasser because the USA's situation was hostile regarding the national policies adopted by him. The USA started some water research of the Nile Basin in the period from 1964 till 1958 for Ethiopia.

Depending on those studies there was a geological survey for the Ethiopian soil in order to present suggestions to build a number of dams on the upstream of the Nile [35].

In regards to the merits of the Ethiopian position, it refused to recognize the two Agreements (the first which was signed by Britain and Italy on the 15th of April, 1891 and the second between Britain and Ethiopia on the 15th of May, 1902). Ethiopia saw that the first Agreement was signed by two occupying states (Britain and Italy) so it bears no obligation towards it according to the theories of "coercion" and "changed circumstances". As for the second Agreement, it was a mere personal promise by Menelik II to Britain, so it is the obligation of the king of kings of Ethiopia as a person not an obligation on the Ethiopian government. In other words, Ethiopia is not obliged to follow its terms and conditions (see [36]).

In 1956, shortly after the liberation of Sudan, Ethiopia declared that it adopts the "Harmon Principle" regarding the Blue Nile (i.e., practicing an absolute sovereignty over the River section running within its territories). Then in 1977, it confirmed its viewpoint in the United Nations conference on water in Mar del Plata, Argentina [37].

In September 1957, Ethiopia addressed a letter to Egypt referring to its natural right to the water which comes from its territories. The note included an implication to the cancellation of the Agreements which Italy signed on behalf of Ethiopia with Egypt regarding the Nile. In addition, Ethiopia refused the Nile water Agreement of 1959 between Egypt and Sudan considering this Agreement as a mere bilateral Agreement between both of them and only these two states bear responsibilities towards it [38].

The study was prepared by Wondimnh Tilahun over "the colonial aspirations of Egypt in the Lake of Tana and Blue Nile." It displayed the Ethiopian pretexts for refusing the former Nile water Agreement. Although Tilahun is an academic professor in Addis Ababa University, the title he chose for his study expresses its subjectivity and its adoption of the opinion claiming that Egypt seeks to control the Nile upstream [39].

Ethiopia views the treaty of 1902 as a treaty over the borders entailing compulsory objective duties and rights on the signatory parties (Ethiopia and Britain), whereas Menilik's promise to the H.M. the king of Britain to refrain from executing any projects on the Nile which may hinder the flow of the water without an Agreement with the British government, was a temporary promise that no upstream state (Ethiopia) would perform any work which may damage a downstream state (Britain at that time) [39]. The right mentioned in this item – according to Ethiopia – is a personal right, so it is not a permanent acquired right. Therefore, there are no legal or historical rights for the Egyptians and Sudanese to demand to be treated as heirs of the alleged British right [40].

The Tanzanian situation was no different. Tanzania refused the Agreements on the water of the Nile. The refusal goes back to the date of Tanganyika independence, then its unity with Zanzibar to form Tanzania in 1964. The Tanzania government – with the instructions of the Tanzanian President at the time, Julius Nyerere – issued a statement known as the "Nyerere Principle" declaring that it is not obliged by the Agreements and treaties signed by its former occupying forces including the Agreement of 1929 [41]. The statement was issued on the 4th of July, 1962, giving the governments of Sudan and Egypt an ultimatum of 2 years (ending on the 4th of July, 1964) during which they should start negotiations with the rest of the Basin states regarding the distribution of the Nile water and the allocation of the water quotas [42].

This statement was supported, joined, and signed by Kenya and Uganda. Then Tanzania, Rwanda, and Burundi signed the Kagera River Agreement in 1977 which adopted – in turn – a refusal to the Agreement of 1929 [43].

The Kenyan situation was similar to that of Ethiopia and Tanzania. Shortly after its independence, it declared that it considers all the historical agreements signed on its behalf void because they jeopardize its sovereignty, and adopted the Nyerere principle. Furthermore, it gave Egypt a period of 2 years to stop the implementation of the historical agreements. This period came to an end on the 12th of December, 1965 (for more details about the historic positions of the upstream Nile countries, see [44]).

Uganda as well declared on its intendance day its obligation of Nyerere principle which refuses the treaties inherited by the Nile Basin states from the occupation era. Similar to Ethiopia, Kenya, and Tanzania, Uganda declared that it does not recognize any agreement or treaty regarding the Nile which was signed without its participation [45].

3.1.2 The Egyptian–Sudanese Position Regarding the Historical Agreements on the Nile Waters

Except for the Sudanese reservation on the Agreement of 1929, the stands of the two states are harmonious. Both – always – asserted the legality of the former Agreements on the Nile waters. The Egyptian justifications which are used to prove the legality of the former Agreements, and consequently prove and assert its rights in these waters depend on two main principles: "the international treaties succession" and "the historical acquired rights."

The International Treaties Succession

The notion of treaty inheritance was the target of international interest for a long time. It was debated on a large scale, especially after the rise of the national independence movement and the independence of the third world states. In 1978, the international efforts exerted by the UN International Law Commission resulted in the signature of Vienna Treaty to organize the inheritance of treaties related to this domain on the 23rd of August, 1978 [46].

The international community distinguished between two sorts of treaties – before Vienna treaty – as far as the possibility of inheriting the terms or the international succession of such treaties. The first sort: includes the treaties governing the international rights and obligations (such as the Agreements on the exploitation of the international Rivers and other waterways dedicated for international navigation purposes such as canals, straits, and bays), in addition to the treaties establishing borders, which regulate the succession of the rights and obligations of borders, allocation from the predecessor state that established the border to the successor state.

The second sort includes the treaties that cannot be inherited and – consequently – do not belong to the domain of the international succession terms such as the contractual treaties (the alliance treaties and the treaties to protection).

Therefore, the borders treaties – eligible for succession – is an exception to what is called "the principle of clean slate" which states that the new state – for being a successor state – is not obliged by any treaty [47].

The 11th Article of the Vienna Treaty went through long and taxing negotiations by the International Law Commission which was responsible for drafting the Agreement draft. The Article asserted the specialty of the borders treaties which declared that: "succession of states does not affect the borders governed by a treaty or the rights and obligations mentioned in a treaty in relation to the system of borders." [48].

Undoubtedly, the success of the commission to include such an Article can be considered a victory to those states that defended the inherited political borders status quo considering that keeping this situation would help many states avoid political disputes regarding the borders, which serve to maintain the international peace and security [46].

International succession of treaties – especially in relation to the borders and the principle of borders sanctity – was debatable among the African states after their independence, especially regarding the inheritance of the political borders or the principle of "borders' sanctity." There were three contexts in relation to the borders inherited from the time of occupation. The first aimed at getting rid of the occupational borders via the achievement of an absolute African unity. The second stressed the importance of achieving the unity in a gradual way, and therefore maintaining the inherited borders as a transitive era. The supporters of the third wanted to avoid the dissection attempts via a final and permanent recognition of the inherited borders the way they are; the third won. Many states in the black continent expressed their interest to maintain their sovereignty and refused the notion of an absolute African unity which the former Ghanaian President Kwame Nkrumah defended [49].

The statements and speeches of the residents and prime ministers of the African States in Addis Ababa Conference on the Establishment of the OAU (1963) expressed this reality. The conference was overwhelmed by a vision that sees that the current borders should be maintained. Many Africans expressed this, such as the President of Mali when he said [50]:

> if a powerful will really motivates us to establish an African unity, we should absorb Africa as it is and give up any territorial demands . . . African unity requires that we respect what we inherited from the occupying forces, in other words maintaining the current borders of our states.

In spite of the lack of containment of the Charter of the Organization of African Unity of a direct reference to the issue of borders, and the absence of any decision on it within the framework of the founding conference participants of the organization in 1963, the congress revealed a general trend among the majority of the African states which is to accept the borders inherited from colonization. This issue was quickly expressed officially in the form of a draft submitted by Tanzania to the Heads of States and Governments in the conference held in Cairo in July 1964 calling for the recognition of borders inherited from the colonial era as a way to reduce the conflicts among the African states. This was the project that has met acceptance of the majority of the African states, and by all Nile states including Ethiopia, resulting in the issuance of Resolution No. (16/1), which urges countries in the Organization of the African Unity to respect the borders inherited from the occupying era. It was considered by the supporters of legal approach in the interpretation of the territorial integrity as the main pillar supporting the stability of the African borders since it gained almost unanimous approval. Only Somalia and the Kingdom of Morocco refused it [51].

The Egyptian situation relied on the principle of treaties inheritance when objecting the pretexts of the Nile upstream states calling for the former agreements on the Nile to be void.

Egypt stresses the importance to comply with the inherited agreements by the Nile Basin states, since they are considered valid in accordance with Articles 11 and 12 of the Vienna Convention of 1978 on the principle of inheritance of the treaties previously signed by the concerned states and governments until a new treaty is drafted [52].

Since an important part of the Convention involved the development of longstanding international norms, some states were expected to refuse any new provisions that would jeopardize these norms.

The statement, made by the Egyptian representative at the meetings of April 1997 and the meeting of the General Assembly on May 21, 1997, expressed the adherence to the stable succession norms of international treaties.

The text elaborating the special relationship between Framework Convention (1997) and other agreements has seen a “game of equilibrium” between the states supporting the principle of “succession of treaties” and those that reject the idea of international succession. However, the final version of the text of paragraph (1) of Article (3) of this Convention was expressive about the viewpoint of the first who called to accept the principle of inheritance of international treaties. The Agreement also gave an opportunity for the states parties to consider if they wish, and on a completely optional basis, the compatibility between the existing agreements and the general rules contained in the new Agreement (according to the text of paragraph “2” of the same Article).

The 5th item of this Article imposes a commitment to negotiate on the basis of good faith in order to hold a watercourse agreement or agreements when a state desires to harmonize the provisions of this convention or its application are necessary due to the special characteristics of the international waterway and its uses [53].

The current phrasing of the 1st item of Article 3 forms a legalization to the general terms of the international law contained in Article (28) of Vienna Convention (1969), it also opposes the 30th Article of the Agreement of 1969 which stresses the importance of succession of treaties. In addition, it copes with the Articles 11 and 12 of Vienna Convention (1978) regarding the application of successive treaties relating to the same subject matter [54].

The phrasing of the third Article (item 1) matches the objective of the Egyptian delegation during the negotiations related to the UN Framework Convention (1997). It hoped that the Agreement should not contain an Article that may affect the former agreements.

The former Egyptian minister of irrigation and water resources, Dr. Mahmoud Abo Zaid stressed a number of facts regarding the Nile water Agreements saying:

> the Nile waters Agreements complement each other and the modern of which confirm what other former Agreements contained. No modern or older Agreement has cancelled former Agreements or opposed the Articles contained in such Agreements. The principle of inheriting the Agreements is one of the international law and customs principles which is applied on the Agreements of the common Rivers. Therefore, the inclusion of the principle of Agreements and treaties inheritance in the international law, the refusal to cancel or amend those Agreements is a logical and humane aspect before being internationally legal since it maintains the life and stability of the lives of peoples and protecting them against and developmental or economic upheaval [55].

The Historic Acquired Right

This principle relies on the necessity to respect the method adopted to share and use the waters of the international among the states located along its waterway provided that this sharing and those uses are implemented for a long time without the objection of the other states, the share becomes of a vital and beneficial importance to the life of such a state.

Due to the fact that the historic acquired rights in the waters of the international rivers have the same importance to the life of the beneficiary state – and an effective role in relation to its creation and civilization – the international jurisprudence described those rights in a way that reflects their core. Some call them the natural rights and some call them the vested rights, while some refer to them as the ancient rights. This signifies that the international jurisprudence considers those rights as a stable foundation to the economic, social, and civilized identity of the states located on the river. Any substantial change regarding the historic shares of the waters would lead – necessarily – to a fatal collapse of the social and economic formation of the state and dangerous effects on the lives of its people [56].

Thus, in an attempt to assert its rights in the Nile waters, Egypt relies on the principle of the "historic acquired right" as one of the basis and principles confirmed by the contemporary jurisprudence and the set of international documents ratified by the states located on the banks of the Nile [57].

The former principle of sharing is considered as a guidance in the equitable sharing of the waters and benefits of international rivers.

The statements of the Egyptians experts and officials in the different meetings and events clarify that the Egyptian justifications depend on the principle of historic acquired right to maintain the Egyptian water rights in the Nile waters [58].

In his reply to the Ethiopian official statements which claim that the Agreement of 1959 is a bilateral Agreement, obliging its parties only, Engineer Esam Rady – the former Minister of Public Works and Water Resources – said:

> the Agreement related to the Nile waters in 1959 is an acquired right based on a former historic Agreement and we cannot to concede our acquired and documented rights [59].

In April 1989, Dr. Abdel Elhadi Radi, the former Minister of Irrigation and Water Resources said:

> the principle of acquired historic rights is a general rule in the international law not limited only to the law governing the international River s in specific. Former dealings with the River is clear and obvious in this regard. The international customary law mentions three conditions, clarified by the International Justice Court in its ruling concerning the Norwegian fisheries in 1951. Those conditions are: the presence of a clear continuous integrated action met by a negative stand by other states which would remain along a specific period of time enough to reach what is called the general moderation of other states, which is a negative satisfaction ... The issue of historic acquired rights is of an undeniable great importance to Egypt, As mentioned in the Agreement of 1959, the quantity of Egypt's historic rights is 55.5 billion cubic meter. This is considered one of Egypt's historic right according to its past and actual uses in the domains of agriculture, drinking water and other vital uses. A right we should adhere to and never let go whatever the circumstances would be [60].

3.2 Conflict over the "Water-Sharing" Between the Nile Basin Countries

The revisions of the rules of the general international law and the law of international rivers show that there is no collective legal base which identifies – precisely – the methods by which the distribution of the international river waters can be distributed when many states share the same river. Yet, the absence of such a rule did not impede on the many attempts exerted by international organizations and researches around the world seeking to reach a number of "standards" and "criterion" which may be qualified as rules and principles governing the distribution of the mutual waters in an international river basin [61].

Helsinki rules – stated by the International Law Association in 1966 – created some standards according to which water can be distributed based on two main principles: reasonableness and justice. The 4th Article stressed the right of every state in the Basin of an international river to benefit from its waters in a reasonable and just way [62], whereas the 5th Article pointed out some of the reasonable and just standards to benefit from the waters of the international River. It stated 11 factors or indications to explain the terms of reasonableness and justice, the reasonable and just share was allocated based on them collectively [63].

The UN Convention on the Law of the Non-Navigational Uses of International Watercourses (May 1997) was concerned with stressing the principle of equitable utilization as a base for the sharing of the mutual water in the international rivers' basins (Article 5) [64].

The subject of water sharing and the standards regulating the distribution of the mutual waters is one of the domains and main dimensions of the water conflicts arising in the Basin from time to time due to the absence of a general Agreement in the Basin to accurately identify how to share the water amongst the states. With the exception of the Agreements of 1929 and 1959 – signed by Egypt and Sudan (upstream and water course states) – about the management of sharing the waters of the Nile, there are no other agreements that state the ways through which the water share could be distributed among all the states in the Basin [65].

Therefore, the distribution of the Nile waters remained "one of the conflicting and sensitive cases" in the relations among the Basin states since some of them tend to bring the case into the light from time to time which increases the conflicting nature of the regional interaction in the Basin. On the one hand, some upstream states demand to reconsider the water distribution and the quotas to avoid the concessions of the downstream and watercourse states which grant them a lion's share of the water. Therefore, those states suggest some of the standards which are considered as having the priority when allocating the waters of the international basin. In contrast, Egypt and Sudan refuse the reallocating of the Nile water. In effect, they suggest some criteria when sharing the waters of the International Basin [66].

3.2.1 The Stands of the Nile Upstream States from the Standers of the Water Sharing

The Nile upstream states adopt a reluctant position towards the way of allocating the waters of the River either in accordance with the Agreement of 1929 or in accordance with the Agreement on the absolute exploitation of the Nile waters ratified by Sudan and Egypt in 1959. The upstream states believe that there are two main standards that should be considered when sharing the waters of the Nile; the space of drainage and the contribution of each state in the water outcome of the River.

Consequently, the upstream states view that the distribution of the water according to the space of each riverine state will provide priorities to Sudan followed by Ethiopian, followed by Egypt, then the rest of the Basin states, i.e. Uganda, Tanzania, Kenya, Eritrea, Democratic Congo, Rwanda, and Burundi, respectively. As for the second standard, we can find that Ethiopia is the biggest contributor followed by Kenya then Tanzania, whereas Sudan contributes with almost 10% of the overall drainage of the Basin, while Egypt's contribution is zero. According to this standard, Ethiopia comes in the first place followed by Kenya then Tanzania as far as the quotas of the Nile waters are concerned; Egypt comes last [67].

Naturally, depending on either of the former two standards does not cope with the practical and scientific logic related to the sharing of water.

3.2.2 The Egyptian–Sudanese Stand from the Water Sharing Standards

The Egyptian–Sudanese viewpoints regarding the sharing of the international rivers water in general, and the waters of the Nile in specific, depend on the principle of fair and just exploitation of the international river sources. Therefore, both states call to apply that principle when considering the allocation of the Nile waters quotas, since each state must obtain a fair and just share [68].

It is clear that the Egyptian water policies maximize some standards which can be relied upon to allocate according to the principle of Equitable and Reasonable Utilization. In the framework, the needs based allocation is a priority, since Egypt and Sudan place relative importance on some standards more than others for the allocation process which are [69]: the extend of the dependence of the inhabitants on the river water, the former (historical) uses, the current and potential uses, and the availability of other water resources.

In this context, the Egyptian situation stressed the necessity to replace the term "International Watercourse" by "International Water Basin" in the light of the framework Agreement, because the term water basin is more general than the term watercourse. The water basin includes three types of water: the surface water that called blue water which consists of rivers and lakes, and the ground water, in addition to the rain water that called green water which plays a major role in the life of the plantation and animals. On the other hand, the term water basin is more general and wider than the term watercourse since the term basin includes the river drainage area and the watershed area. Whereas the term course refers only to the course of the water. Thirdly, considering the term international water basin will not affect the acquired rights and the obligations stated in regional, bilateral agreements or stable customary relations among the international basin states in any way [70].

3.2.3 The Stand of the Nile Upstream Countries Regarding Selling the Waters of the Nile River

Some of the Nile Basin upstream states refuse to allocate the waters of the Nile in accordance with the Agreement on absolute use of the Nile waters signed by Egypt and Sudan in 1959. Some of those states demand to reconsider this way so that the downstream and middle stream states do not get the biggest share of the cake. They demand to reallocate the shares for the states located on the banks of the River. In addition, those states demanded that Egypt and Sudan should pay fees against the water quotas if they wish to keep them continually. In other words, some of the upstream states call for the generalization of the "international water trade" term and to apply it on the Nile Basin system [71]. Thus, they demand Egypt and Sudan to pay fees against their annual share of the Nile waters which comes from their territories and flows into both states, especially that they contribute only with 1% of the River waters.

Nile upstream countries experience extreme poverty and low standards of living [72]. It is expected that, in light of the large population increase in the Nile Basin countries, there will be an increase in demand water for development [73].

3.2.4 The Egyptian–Sudanese Stand Regarding Selling the Waters of the Nile River

Both Sudanese and Egyptian experts and officials interested in the water issues agree on refusing the principle of the international water trade in form and substance. The refusal is based on the reluctance to consider water as an economic good which can be sold and bought. Egypt opposed this idea in many international events. The experts and officials of irrigation in both states – who were interviewed by the researcher – agree that "the water is not an economic good, in spite of its huge economic value which cannot be ignored; but we cannot omit the social dimensions of this water. Therefore, it cannot be subjected to the mechanisms of the free market without consideration of the social dimensions of this important and crucial resource. In addition to the fact that considering water as an economic good may have negative impacts on the regional stability of the Nile Basin".

In this context, the researcher tends to oppose the water trade notion. The justification for this refusal is that this strategy – even with agreement among the states having abundance of water and those suffering from its scarcity – will result in the eruption of water conflicts and wars among those states in the medium and long term ranges. That is because the exporting states may cease the exporting process due to a change in the factors of water supply and demand because of the population growth and the increase of their human, industrial, and agricultural development requirements. On the other hand, the importing states may have planned its development projects and other life aspects in accordance with the imported waters, hence, they may consider the ceasing of selling the water as a hostile action. This situation – if it takes place – would lead to countless risks and conflicts in the future.

In addition to that, the researcher sees that the geographical constants and the climatic facts oppose "Nile water trade" which some of the upstream states adopt via the following considerations:

Firstly, the natural course of the River from its beginning from the tropical and Ethiopian upstream shows that the natural flow – according to the surface gradient – drives the water naturally – without any human intervention – towards the Mediterranean. The flowing of the water into the downstream and middle stream states is naturally managed by the topographical, hydrological, and metrological characteristics of the River and its basin, this proves the right of the downstream and middle stream states in the natural outcome of the River which they obtain. Hence, the allegations that the upstream states have a right to sell the Nile waters to Egypt and Sudan is a mutilation of the natural phenomenon which distinguishes the hydrological behavior of the River starting from its upstream to its downstream.

Secondly, if we accept the allegations that the upstream states have the right to sell the Nile water to Egypt and Sudan – with the same logic – the states in which the rainy clouds are formed have the right to demand fees against the rains falling on the upstream states. Therefore, those states have no right to demand fees from Egypt and Sudan against the water that flows naturally into their territories, the same way they cannot be asked to pay fees for the rainy clouds.

3.3 The Conflict over the "Prior Notification Condition" Among the Nile Basin States

Obliging to prior notification or consultation and to refrain from causing harm is probably the most debatable issue in connection with the international law. The obligation of the riparian states to notify others of planned projects that may cause significant harm could help avoid conflicts among these states.

International relations among the upstream and downstream states show that the regional water projects executed by a state within its local territories raise the concern of many states, especially among the downstream states which become concerned that those projects may affect the water projects executed by one or more upstream states as far as quantity and natural water flow is concerned (we can refer to the Syrian-Iraqi concerned (downstream states) towards the potential Turkish water project in Southeast of Anatolia (GAP) on Tigris-Euphrates. For more details, see [74]).

3.3.1 The Egyptian–Sudanese Situation Regarding the Prior Notification Condition

As middle and downstream states, Egypt and Sudan assert the importance of the "prior notification condition" and adhere to it. They call to consider it among the essential rules within the Nile Basin and insist on applying it by the downstream states as an essential request before the initiation of any procedures or steps by the upstream states of any individual; or collective projects on the Basin or on a section of it, especially on the Blue Nile, in order to assert that such projects do not constitute damage or entail negative consequences on the quantity or quality of the naturally flowing water into the tow downstream states [75].

Therefore, Egypt rejects Ethiopian dams to be built because Ethiopia does not meet the requirement of prior notification and the announcement of the construction of these dams [76].

On the 29th of April, 1984, the former Egyptian Minister of Irrigation made a statement before the Shura Council (a former parliamentary chamber) saying:

> The recognition of the principle to notify and consult other states when executing any projects on the Nile is an objective we must achieve by all means to ban the upstream states from the execution of whatever projects they desire in a way that will affect the present and future Nile resources [77].

In the same context, in March of 2003, Dr. Mahmoud Abu Zaid, the former Egyptian Irrigation Minister said:

> The core of the mutual rivers agreements generally whether on the Nile or any other international river, is to ban the execution of any projects by upstream states that may affect the downstream states [78].

In addition, Dr. Mohamed Nasr Eldin Allam – the former Egyptian Irrigation Minster – asserted that the obligation to present prior notification by the downstream states when executing any regional water projects is one of the constants of the Egyptian water policy which is not subject to negotiation or abdication [79]. All ministers and officials of the water resources in both Egypt and Sudan interviewed by the researcher confirmed this.

3.3.2 The Position of the Nile Upstream Countries Towards the Prior Notification Condition

The Nile upstream states refuse the prior notification condition when executing regional water projects or when they plan to carry on water procedures within their national territories. This situation adopted by most of the Nile upstream states depends on the pretexts of the theory of absolute territorial sovereignty which is also called "Harmon doctrine." This theory states that each riverine state has the right to take any steps necessary to convert the course of the River, affect its waters, or use such waters freely regardless of the consequences that the downstream states would suffer from [9].

The reasons of this refusal are: firstly, most of the Nile upstream states refuse the former agreements related to the Nile especially the Agreements of 1929 and 1959 which – both – asserted the prior notification condition [29]. The second reason is that the Nile upstream states adhere to the "exchanging" implementation of the prior notification condition. They call, especially Ethiopia which leads this camp, for the obligation to have it as a bilateral commitment which must be applied on both upstream and downstream states [80].

Therefore, both Ethiopia and other upstream states demand that Egypt and Sudan must provide them with prior notification when taking any steps and procedures or executing projects. If Egypt and Sudan do not comply, the upstream states' obligation is void [81].

Through history, the Ethiopia emperors advocated the "Ethiopian control on the Nile upstream and the ability to convert the course of the Blue Nile to place a political and economic pressure on both Egypt and Sudan." Ethiopia did not hesitate to declare that its abundant water resources are a gift it can freely exploit.

In 1680 the Ethiopian King Tekle Haymanot threatened the Egyptian governor saying: "the Nile is enough to punish you. The Lord has placed its upstream, lake and development in our hands and it can be our tool to harm you" [82].

In this context, Ethiopia agreed with the USA to carry out an overall study for agricultural and power generation projects that can be implemented in the Nile Basin in Ethiopia. When the USA withdrew its offer to finance the Aswan High Dam in 1965, it claimed that this was due to the absence of a comprehensive agreement between Egypt and the upstream Nile countries. Thus, it is clear that the Nile was a source for the political conflict among the superpowers [83].

Naturally, Egypt and Ethiopia were part of this conflict and that led to bad relations between the two states. In the eyes of Egypt's Nasser, Ethiopia is a hostile state especially after it signed a military agreement with the USA in 1953 and received an Israeli general consulate to Addis Ababa in 1965. As a reaction, Egypt assisted the Eritrean separatists and backed Somalia during its conflict with Ethiopia. In addition, Egypt encouraged the "Grand Somalia" notion in order to weaken the Ethiopian front and ban it from using the Nile to pressure the Egyptian policies [84].

The problem was escalated when Ethiopia declared in the "Ethiopian Herald" in February, 1956: "Ethiopia is no longer obliged by the Agreements and protocols signed during Minilik II era and it has the right to exploit the waters of the Nile that runs within its territories." Then came a number of statements asserting that Ethiopia has the right to execute any plans or projects necessary for its economy or to meet its water, agriculture, and power needs. To assert the seriousness of this stand, it enlisted those objective in a letter addressed to all the diplomatic missions in Cairo [85].

The political dispute remained between Egypt and Ethiopia in 1970s. In 1974, the Marxist revolution erupted in Ethiopia under the leadership of Mengistu Haile Mariam. It succeeded in overthrowing the Haile Selassie system by a coup. Then Ethiopia's tendencies were directed towards the USSR which opposed the Egyptian–US agreements. This conflict was clear with the Egyptian support to

Somalia during its war with Ethiopia over the Ogden desert. This was similar in regard to the Eretria Liberation Front during its armed conflict with Ethiopia in an application that obtained a semi-consensus in the first African summit held in Addis Ababa (1963) (see [86]).

The Egyptian–Ethiopian political conflicts during 1970s were reflected on the Nile waters issue as an example of the international conflicts which prevailed in Africa and the Middle East in this period [87].

In no time, the hydropolitical conflicts between the two states were escalated when President Anwar Al-Sadat announced in Haifa (on the 6th of September, 1979) – as a part of a political maneuver plan with Israel to achieve more advantages during his negotiations with the later – that he intends to convert a section of the Nile so that its waters could reach the Naqab desert via the Sinai. He said: " this will be the base for the principle of good neighboring". Consequently, he ordered the Minister of Irrigation to execute a complete study on the transportation system on the Nile waters to Jerusalem across the Naqab desert [88].

In May, 1980, Ethiopia presented a memorandum to OAU complaining and protesting the statements of Sadat, threatening that it will divert the Nile course by any means including the use of the military powers, if necessary [89]. Additionally, one of the studies published in "Eno Scope" magazine (issued by the journalism and media department of the Ethiopian Foreign Affairs Ministry) in 1994 suggested the establishment of a number of projects for water storage and power generation on the Blue Nile [90].

In the same context, the Ethiopian parliament accepted on the 9th of June, 1996 the government's request to establish two reservoirs on the most important tributaries of the Nile to allow the country to exploit its economic capabilities and its natural resources. The first is a huge reservoir on the Blue Nile for agricultural purposes and to generate electric power, and the second is smaller on "Dabbous" River. The International Bank and other entities were to finance the project [91].

In addition, Ethiopia finished a number of dams, including (for more details about these projects, see [92]): Tekeze Hydropower dam, Belesse hydropower dam, Genale Dawa III dam, Chemoga Yeda and Gilgel Gibe dam.

The Ethiopian Prime Minister Meles Zenawi commented on those projects and other issues related to the water relations in the Nile Basin region saying: "dams projects are part of the internal programs of the current democratic regime in Ethiopia." The establishments of those dams are included in the internal programs of the Ethiopian government to fight famine and desertification, as well as hydropower generation (see the article [93]).

3.3.3 Analysis of the Ethiopian Hydropolitical Behavior Towards Renaissance Dam

The analysis of the Ethiopian situations in regard to the Renaissance Dam clarifies the Ethiopian politicization of the Nile waters issue in order to achieve political and strategic objectives; along with the developmental goals (for more details, see [94]). The following points affirm this conclusion:

Ethiopia Seeks to Impose a Hydropolitical Hegemony on the Nile Basin Which means transforming the hydro-hegemony into hydropolitical and hydro-strategic [95] since it realizes that it contributes the largest amounts of water into the Nile. Therefore, it seeks to interpret this hydro-hegemony into hydropolitical and hydro-strategic on the regional system of the Nile [96]. The Renaissance Dam is one of the mechanisms to achieve this objective on the Eastern Nile Basin [97].

As an assertion of the hydropolitical hegemony, Ethiopia intended to build three other dams on the Blue Nile to have a full control over the flowing waters reaching Egypt. Those dams are: “Mendiya,” “Bako Abo,” and “Kara Dobi,” aiming to raise the water level in Tana lake (upstream of the Blue Nile) or to change the River course whenever desired [98].

Ethiopia has amended the technical specifications of the four dams so that their capacity reached 200 billion cubic meters instead of 50 billion, in a clear challenge to the Egyptian water interests and as a sever threat to the Egyptian water security [99]. Ethiopia concealed objectives beyond the establishment of those dams to achieve a hydropolitical hegemony over Egypt and put it under a water siege, and consequently, placing it under a political and strategic siege in order to impose political and strategic settlements on Egypt and change the strategic balance interactions in the Nile Basin regions so that the leadership of the region becomes fully Ethiopia dominated [100].

As an evidence of Ethiopia’s objective, the height and size of the Nada dam was maximized more than needed although this has affected the efficiency of the dam to generate power [101].

In the US study, the dam specifications were more appropriate, more efficient, and cheaper. This asserts the notion that the Renaissance Dam – with these technical specifications – is established to harm the Egyptian interests and put severe pressure on it to pave the way for the Ethiopian hydropolitical hegemony.

In this domain, Professor Asfaw Beyene – a professor of mechanical engineering and director of the renewable energy in Saint Diego university, USA – asserts that there is an unjustified exaggeration of the dam size technically. He wonders: “what is the reason to build a dam with that height and with that capacity if its purpose is only power generation” [102]. It is worth mentioning that he is an Ethiopian national.

In another study, prepared by Beyene, he stated that the Renaissance Dam is useless as far as electricity is concerned since it has a low efficiency to generate power due to its exaggerated size and height [103].

Ethiopia Adopts a Fait Accompli Policy: Since the end of 1950s, the Ethiopian policies expressed a desire to impose a fait accompli policy through a chain of projects which it started in cooperation with the US Bureau of Reclamation [104]. There was an increase in the number of plans to establish dams on the Nile tributaries during the last decade. Ethiopia completed the Tekeze hydropower Dam and Belesse Hydropower Dam. Later it started the establishment of the Renaissance Dam without any notification to the downstream state (Egypt).

This policy was clearly exposed when a trio committee was formed to evaluate the dam in 2012. The Ethiopians insisted that the primary documents should state that the "Renaissance dam is under construction" and refused the suggested phrasing presented by Egypt and Sudan completely. Their phrasing stated that it is "a potential dam." The Egyptian negotiator was forced to accept the Ethiopian wording.

The Ethiopian side waged a physiological war when sending notes either via its officials or diplomats in an attempt to convince the Egyptians that it should accept the status quo which is that the dam will be built regardless of the recommendations of the committee [105].

Ethiopia's noncompliance with the "prior notification "condition and its breach of an international law principle broke good neighboring notions and avoidance of harm, which resulted of it falling under international legal responsibility. In addition, it succeeded in minimizing the mentioned issue to the extent that it faded and tricked the Egyptian negotiators into the fragmentation of the case in question [106].

The trick was clear from the start since Ethiopia aimed to prolong the negotiations in the light its "negotiations strategy" which is based on gaining time, delay, and intransigence gratuitous.

The Ethiopian Moves are Individual, Unilateral, and Lack Coordination with the Basin States and Egypt, in Specific Since it does not believe in the importance of the "prior notification condition" before the execution of its water projects on the Nile tributaries and insists that it has an absolute right to deal with the section of the River running on its territories freely without any cooperation with Egypt or any other basin state [29].

In this context, professor Zewde Gobre – Sellassie – at Addis Ababa University – asserted in a lecture delivered during the conference arranged by Tel Aviv University in May 1997 that the Ethiopians believe – since 1950 – that they have a right to the waters of the Nile, therefore Ethiopia has the right to execute any project contained in the study of the US Bureau (1964) to meet its needs [107].

While professor Harold G. Marcus – from Michigan university – dealt with the subject of the Ethiopian water projects in a lecture delivered in the same conference, where he mentioned that the Ethiopians threatened many times to execute projects that can prevent the flow of the Blue Nile waters so that they can push Egypt to give some concessions, the technology needed for this was not yet available but emperor Haile Selassie hoped to execute these projects to generate the electricity much needed for the African development projects and sell the water to Sudan and Egypt.

Yet, due to the Ethiopian weakness, Haile Selassie did not manage to obstruct the Nile waters treaties. Marcus mentioned that the emperor awarded an engineering office in New York to study the possibility of building a dam in Ethiopia on Tana lake to control the flow of the Blue Nile for the purpose of power generation and to irrigate many areas in the state [108].

The hostile side of the Ethiopian Hydropolitics towards Egypt lies in the fact that it does not call only to adopt the "Harmon theory" but call the Nile a "Transboundary

River" [109] instead of calling it an international river. The latter is more accurate as stated in all the agreements on international rivers signed by many states starting from the Barcelona Agreement regarding navigation in the international rivers (1921) then the Helsinki Doctrine on the international rivers basins (1966), and finally the Convention on the Law of the Non-Navigational Uses of International Watercourses (1997) [110].

The term "transboundary river" – as adopted by Turkey and Ethiopia – constitutes a political danger since the implication of the term is far dangerous than it seems.

Explicitly the River is internal, so it is subject to the absolute sovereignty of the upstream state but it crosses the borders of this state, but this crossing does not affect or limit the absolute sovereignty of the upstream state on it (it is worth mentioning that the term "transboundary river" was mentioned in the summary of the technical report issued by the technical commission which was assigned to evaluate the effects of Renaissance dam and the Egyptian side had no reaction towards this serious issue).

Ethiopia's individual and unilateral moves and its reluctance to coordinate with the Nile Basin states, especially Egypt, does not only affect the style of the hydropolitical transaction in the Basin negatively, but may also sometimes damage the Ethiopia's own interests The evidence lies in the negative impacts on the Ethiopian national stock reserves since the creation of a lake in front of the dam will submerge some of the most important mining areas in the country which host major stocks like gold, platinum, iron, brass, and some of the stone-pits [111].

In addition, the lake will submerge more than half a million acres of woods and agricultural fields. Those areas cannot be re-cultivated or restored because the areas that can be cultivated in the Blue Nile Basin are limited to the West of Ethiopia, i.e. in the Blue Nile Basin area [112]. The hydropolitical hegemony remains the main objective of Ethiopia.

Ethiopian Aims to Change the Hydropolitical and Hydro-Strategic Balance in the Water Regional System of the Nile Basin Through its water politics in the Nile Basin making an "initiator" of itself or an "actor" who does the act and the others are "subjects" or the ones who react since Ethiopia is the one that identifies the "risks" in the Nile Basin and decides – in the time appropriate for itself – which dams to build.

It also accuses the upstream Egypt with "the desire to wage a water war" and "incite Eritrea against Ethiopia."

In addition, Ethiopia decides – solely – and in the time it wishes that the "Egyptian interests will not be harmed due to the Ethiopian dams." [113].

In other words, Ethiopia desires to establish a new reality where it becomes "the regional actor" or the "regional dominator" on the regional system of the Nile Basin [114].

To establish this new reality and in order to achieve a regional hydropolitical hegemony, it alleges that Egypt and Sudan obtain 90% of the River waters and calls for "equal" allocation [115].

On the other hand, Egypt replies by asserting the principle of fair and just use of the River resources. The amounts of rain on the Nile Basin exceeds 1,660 billion cubic meter/year, Egypt and Sudan obtain 84 billion only, which equals 5% of the total amount, while Ethiopia and other upstream states obtain the green waters which are reserved underground benefiting the natural meadows. The rain water which falls on Ethiopian areas located in the Nile Basin is approximately 900 billion cubic meters.

Ethiopia claims that it has the right to obtain water quotas equal to those obtained by Egypt due to the number of its population since it is equal to that of Egypt’s. But those allegations are groundless since Egypt is the only Nile state whose citizens live in the Nile Valley (96% of the Egyptians). Therefore it depends on the Nile almost completely while only 39.5% of the Ethiopians live in the Nile Basin while the rest live in the Basins of other rivers running within its territories.

On the other hand, in its reply to Ethiopia’s alleges that Egypt declared that it does not obstruct the development in any basin state including Ethiopia. It did not object the Tekeze Dam which was built in 2009 in Ethiopia with a capacity of nine billion cubic meters and did not object The Tana Pelace power generation project which was executed in 2010 since both have a limited impact on Egypt [116].

Ethiopian employs the regional and international contexts to achieve its strategic objectives. On the international level, it employs the strategic conflict of interests with Egypt in Africa, on the one hand, and the current superpower (USA), on the other. In light of the US attempt to achieve geostrategic hegemony in the African continent through its alliance with some regional powers, namely Ethiopia, Ethiopia under Prime Minister Meles Zenawi presented succeeded in the last 2 decades to present itself as a potential ally that could protect the American interests in the Horn of Africa. This endangers Egyptian interests in the Nile basin, especially with the absence of any strong strategic relations between Egypt and any other superpowers that can be employed for political maneuvers with USA [117].

On the regional level, Ethiopia succeeded – to some extent – to establish which it calls a “special relation” with Israel.

Hence, it employs the Israeli hegemony over the Middle East with the help of the USA, exploiting the Egyptian distraction due to the internal and external files doubling the negative consequences and impacts on the hydropolitical transaction in the Nile Basin [118].

Consequently, Prince Khalid Ben Sultan – the director of the Arab Council for water – summarized the hydropolitical situation of the Renaissance dam saying:

> The dam will cause a deliberate harm to the Egyptian rights in the Nile and will jeopardize the water potentialities of both Egypt and Sudan. Egypt will be the main loser from the establishment of the Renaissance dam because it possesses no water alternatives similar to the rest of the Nile Basin states. The establishment of this dam is a political hostility not an economic gain.

The Kenyan situation is not different from that of Ethiopia’s, yet it is less aggressive. Kenya was satisfied with implying that it can execute projects aiming at exploiting the waters of the rivers and tributaries running on its territories before flowing into Lake Victoria. Naturally, such a procedure would negatively affect the amount of water reaching Egypt and Sudan. Examples on those projects are: the potential Kenyan projects to convert some of the tributaries of Lake Victoria to flow into Kerio Valley, especially that the Kenyan parliament already formed a specialized commission to develop this valley [9].

Tanzania went down the same path. There was always a gesture implying that there will be water projects established on the Nile and its tributaries without consulting Egypt [119].

The Tanzanian government has discussed a project to cultivate the Vambre Hill in the middle of the country. The project's objective is to convert a part of Lake Victoria waters to this area to cultivate 550,000 acre to plant cotton. It is an old project suggested by the Germans during the German occupation of the area.

In addition, the Tanzanian government suggested another project to be established in cooperation with the rest of Kagera basin states (Kagera is one of Lake Victoria's tributary) to exploit the Basin waters.

The states formed an organization to exploit Kagera River (The Kagera Basin Organization (KBO) was formed by Burundi, Rwanda, Tanzania, and Uganda to manage Kagera basin, the organization was initiated on 24 August 1977. For more details, see [120]). They established the Rusumo Dam to generate power. They also studied the agricultural potentialities in the Basin, they concluded that they can focus on three small areas to cultivate 15,600 acres in Rwanda, Burundi, and Tanzania. The projects stopped as a result of the absence of sufficient finances in addition to the conflicts that erupted in the region [121].

Uganda declared its refusal to the Agreement of 1929 explaining that it does not include prior notification or consultation condition in spite of the fact that it signed the Agreement of 1953 which stressed the obligations of the 1929 Agreement. Then, after its independence, it signed the Agreement of 1991 with Egypt which stressed the obligations contained in the former two Agreements [122].

Both Rwanda and Burundi plan to execute developmental projects on the Kagera River. Some of the reports issued by the specialized national councils estimated the amounts of water which will be deducted from Lake Victoria, if those projects are established, by approximately one billion cubic meter/year [123].

4 The Role of the Regional and Regional Actors in the Nile Basin

External forces or what can be called "third party" play an effective role in the regional systems transitions through its impact on the regional system types, i.e. the relations taking place within the regional systems (conflicting or cooperative).

Therefore the term “externality” applies to the impacts caused by an external party on a state (or states) party to the regional system against another state within it [124].

The role played by external powers in the regional systems types may be a stimulant for an international conflict.

Some of the external parties may create dispute among the regional system’s units, and they may play a “stimulant” role to enhance cooperation with the regional units [125], whereas external threats may lead to a system split and constitute a threat to stability if they are supported from inside the regional system. The “external threat” can be transformed to be a source for regional conflict (about the concept of regional threats and their relation to security and stability, see [126]).

It cannot be ignored that the external party may sometimes stimulate cooperation and integrity.

Wriggins identified the methods or approaches of the external parties’ (foreign powers) intervention in the regional systems’ affairs [127] as:

- The external state or power has direct economic and strategic interests in the region or has a special relation within one of its parties.
- Competitions over hegemony areas between the superpowers in the global system.
- Intervention of external power (or powers) as a response to a demand by one of the regional system states to balance the power of another state in the region which seeks to expand its hegemony on the account of the inviting state.

Generally, some regional and international powers play a variety of roles in the Nile Basin, ranging from encouraging conflicts and cooperation among the Basin states.

4.1 The US Role in the Nile Basin

The USA has no direct water coverts in the Nile waters. Yet, it has political motives in the area to maintain its interests via enhancing its geostrategic hegemony and empowering its allies – whether those be inside the Basin area such as Ethiopia or outside it such as Israel – in order to achieve political and strategic advantages, even if those policies were on the account of the vital Egyptian interests.

When considering the geopolitical map of the Nile Basin, the reason for US interest in the region will be obvious. Egypt lies in North and is connected to the Great Lakes through a natural extension that reaches the middle of the continent, and is connected with the African horn area and with the Red Sea. Also, those factors are directly connected to the security to the state of Israel which the USA works hard to maintain as a strategic ally to maintain – consequently – its own interests in the region [128].

The US role in the Nile Basin is related to interests that focus on controlling the oil wells and its transportation paths. Another interest is the support of Israeli existence as a tool to facilitate this control and obstacle any radical movements in the region that may affect the US interests [129].

Since the 1950s, the US existence in Ethiopia remained in support of the Israel and constituted a siege around the Arab national security [130].

In the 1960s, the US economic and political support to Israel came in a variety of forms, in addition to the military aid offered to Ethiopia by the USA [131].

In the 1970s, the US policies in Africa focused on supporting Israel's attempt to re-establish diplomatic relationships with African states [132].

In the 1980s, the USA made plans to enhance Israeli presence in Africa via financing Israeli aid programs directed to Africa and placing US funds and equipment under Israeli disposal [133].

Both Joyce Starr and Daniel Stoll assert that since the 1950s, the USA executed many technical aid plans in the Middle East to achieve its objectives, including building dams [134], through many ministries and agencies.

After the Cold War, the USA had the sole control over the African Horn after the withdrawal of USSR. It expressed its desire that the Red Sea and Mandeb strait not fall under the control of any state that is not an ally [135].

Some analysts consider the US–Ethiopian partnership as a part of the US attempts to prepare Ethiopia to become the central leader of the Nile region [136].

With the start of the twentieth century, the USA adopted "a new policy towards Africa" aiming at tightening its fists on the continent as a whole via the possession of political and geostrategic influence, in addition to allowing its traditional allies to penetrate strategically in Africa via the formation of geostrategic relations and partnerships with some of the states [137].

Moreover, the USA wanted to achieve hegemony policies on the African continent via two strategies: the USA Africa Command (AFRICOM) and "the Great African Horn Project."

4.1.1 US Military Command (AFRICOM)

On the 1st of October, 2008, the US Military Command (AFRICOM) started officially [138]. The forming of this unit constitutes a significant turning point in the international Pentagon map granting Africa a bigger weight in the light of the US increasing interest in the African oil [139].

This "tradition" can be considered a consequences of the 9/11 attacks after which the US administration waged a war on terrorism on grounds thousands of kilometers away from its own [140].

The main objective for forming this command is to create a stable environment in Africa to encourage the establishment of civil societies and improve the living standards of the continent's peoples [141]. Its mission was to defuse conflicts and maintain a secure environment against the dangers of Al-Qaeda [142].

4.1.2 The USA and the "Greater Horn of Africa" Initiative

The African Horn region represents a special geopolitical importance. So, the USA developed an interest in the area due to many considerations including the discovery of oil. Therefore, many US oil companies paid great attention to Sudanese oil developments.

The former US President Bill Clinton declared a Presidential initiative at the end of 1994 which was called: "The initiative of the Great African Horn." The US strategy included 8 states, the only excluded Nile Basin states were Egypt and the Democratic Congo [143].

In the framework of the US strategy in the African Horn area, Vance Serchuk – a researcher in the American Enterprise institution – believed that the development that attracted the attention was the US acceptance of the Ethiopian military intervention in Somalia; enforcing the Ethiopian military power to execute its mission successfully in the light of the strategy which the Pentagon adopted [144].

On the level of the relations with Ethiopia, one of the reports issued by CSIS in January 2006 titled: "Ethiopia: 2005, the beginning of change," stated that the USA had close and supporting relations with Ethiopia since the Ethiopian People's Revolutionary Democratic Front took over the country in 1991. Clinton's administration considered Meles Zenawi one of the new generation promising leaders.

After 9/11, the relations between Washington and Addis Ababa reached new horizons with their cooperation regarding the war against terrorism especially as a result of the fear both sides felt from the Islamic Somali Al-Shabaab organization.

Moreover, in the framework of their escalating security relations, Washington supplied Addis Ababa with military and training aid in addition to economic support.

This does not only apply to the USA, Zenawi got the support of donors such as Britain. This support was obvious in the report of the Commission Concerned with the African Affairs (2004–2005) formed by the British Prime Minister Tony Blair [145].

On the other hand, US policies towards Ethiopia were mostly affected by the huge mobilization efforts exerted by the Ethiopian Diaspora within the USA, a large community that is relatively wealthy and well organized. The Ethiopian–Americans succeeded in developing relations with a number of congressmen and managed to put some pressure on the American administration to change its policies towards Ethiopia [146].

It is worth mentioning that in 2012, a report was issued by one of the American Intelligence Agencies titled: "The International Water Security." Eight US governmental institutions – including the CIA – cooperated to issue the report. It contained an analysis of the international water crisis. Notably, the report arranged the international rivers according to their importance to the American national security. Thus, it focused on analyzing the states that can be considered – strategically – more important to the USA and is linked to many intercontinental cases via the water basins to which they belong. The Nile came first on the list followed by Tigris and Euphrates Rivers, as well as the Mekong, Jordan, Andos, Brahmaputra, and Amu Darya, respectively.

Placing the Nile as a top priority for the US external water policies has a very significant political implication. This report is sufficient to clarify the interactions between the water challenges and the US national security [147].

Thus, we can conclude that the new US security and strategic projects executed in Africa during the last decade – whether AFRCOM or the Great African Horn Project – assert that there are US moves in the Nile Basin aiming at maintaining the US interests via the enhancement of its political and geostrategic hegemony and paving the way for the Israeli influence. In addition, there was the creation of cooperation frameworks with Ethiopia in order to put the Arab policies – generally – and the Egyptian–Sudanese policies – specifically – under siege. In this sense, the US role stimulates the water conflicts in the Nile Basin.

4.2 The Israeli Role in the Nile Basin

There are evidence and indicators that there is an obvious Israeli role in the Nile Basin. This role depends on two main stable and firm determinants which are the basics for the Israeli water policies to implement two constant and simultaneous strategies in the Nile Basin.

The two determinants are: the centrality of water in the Israeli strategic plan and the water poverty which it suffers from. The two strategies are: the Israeli projects strategy which aims to obtain a share of the Nile waters and the strategy to "surround" the Egyptian regional policy politically and strategically in order to weaken it.

The first determinant is linked to Israeli water poverty, while the second determinant is linked to the importance of water in the Israeli strategic plan which urges it to adopt the doctrine of "water militarization" in the Israeli national security theory. The writings and statements of the founders of the Hebrew State asserted the importance of water in their attempts to establish Israel [148].

In other words, the water dimension was present when forming the geographic dimensions as the factor on which the project depends to succeed, continue, and flourish [149]. The definition of "secure borders" includes the upstream regions especially the rivers of Jordon, Yarmouk, Litany and the waters of Mount Hermon [150].

Therefore, Theodor Herzl, the founder of the modern Zionist movement and founder of Israel believed that the real founders of the new–old land are the water engineers, and everything depends on them [151].

The historical-political incidents assert that water is the basic for the foundation of the Jew nation and the water resources are the boundaries of this nation [152].

In this direction, the Hebrew state adopted two water strategies; the quotas strategy, considering the water projects that enable Israel to obtain a stable quota from the Nile waters [153] and Hertzl Project (1903), in addition to Elisha Cali

Project (1974) which both planned to transport the Nile waters to Israel across Sinai [154].

Then, there is the "containment strategy," which is besieging the Egyptian politics in the Nile River via distracting Egypt through stimulating disturbances sometimes and conflicts on other times to influence its regional surroundings. For this purpose it uses the "penetration mechanism" whose indicators are obvious in many ways whether economic, political, military, or cultural.

So, Israeli seeks to strengthen its relations with the Basin states in the domains of commercial, agricultural, and water exchange [155].

In this context, the Israeli–Ethiopian convergence can be explained considering that Ethiopia controls 85% of the Nile water resources and hosts its main upstream, in addition to political factors such as the historical disturbed Egyptian–Ethiopian relations and the geostrategic factors such as the acting presence of Ethiopia in the African Horn area.

Therefore, the Ethiopian–Israeli convergence is on the account of the Egyptian status in the water region and puts more pressure on Egyptian national security [156].

The objective of the Israeli penetration in the Nile Basin is to achieve the strategic targets of the Israeli security theory which is to enable Israel to besiege the Arab states – especially Egypt – and deprive it from any influence in Africa.

There is a variety of indicators, mechanisms, and demonstrations of the Israeli penetration in the Nile Basin politically, militarily, economically, culturally, and related to water [157]. To conclude, the Israeli role in the Nile Basin stimulates the international conflicts.

4.3 The Chinese Role in the Nile Basin

Historically, China had no role in the water interactions (conflicting or cooperative) of the Nile Basin since it has no water intentions in the Nile.

Yet, the notable ascendance of China as an economic and commercial superpower, whose influence reaches different international markets and regions, especially the big expansion of the grand Chinese investment companies all around Africa, made China one of the major international actors in the political, economic, and strategic relations within the continent (for more details about the rise of china, see [158]). This has been obvious with the massive presence of the Chinese construction and contractor companies and their significant role in the establishment of a number of dams and water reservoirs in some Nile upstream states [159].

The Institute for Security and Development in Stockholm issued a report about "China and Africa" prepared by Prof. George T. Yu, the former director of the center for Asian and the Pacific Studies at Illinois University-USA in the period from 1992 till 2004.

The report sheds light on the current debates regarding the escalating Chinese role in the black continent and its reasons [160]. China directed its diplomacy towards the African states during the past and present to achieve a variety of objectives according to the regional and international circumstances that prevail from time to time.

In this context, it depended on three tools, the first is the official aid, the commercial relations and investment. The second is the cultural tools which played a major role especially that its main target was to create a positive image of China in order to employ this image in the domain of the Chinese–African relations. The third is personal diplomacy. The three tools – in addition to the technical aid – contributed to the development of the relations between the two parties on the level of international partnership [161].

The political and strategic influence of China on the Nile Basin water interactions is obvious in the first decade of the twenty-first century via awarding many engineering contractors to establish – or participate in the establishment – of many dams and reservoirs in some of the upstream Nile states. Some of the most important dams China established in those states are: Tekeze Hydropower dam, Genale Dawa III dam, and Chemoga Yeda dam (for more details on this topic, see [162]).

The Chinese influence on the hydropolitics interactions in the Nile Basin can be evaluated from two perspectives.

The first is the perspective of the upstream states. They evaluate the Chinese role positively since they see that its role in establishing and building the water projects – dams and reservoirs – can be considered a developmental role which contributes to the enhancement of the society development in those states.

The second is the Egyptian–Sudanese perspective (the middle and downstream states). They evaluate the Chinese role negatively because the Chinese contractors executing those projects in the upstream states did not comply with the "prior notification condition" before the execution of any of these projects which could be met with an Egyptian–Sudanese objections.

Consequently, some conflicting interactions can erupt due to the Chinese economic-engineering policy in the Nile Basin (see [163]).

4.4 The Role of the International Donors in the Nile Basin

Some of the grand international powers – European and non-European – play the role of donors for some developmental and water projects in the upstream states. Therefore they influence the hydropolitical transactions in the Nile Basin.

These powers can be classified into two main categories: European and non-European powers.

Italy, Holland, and Germany belong to this category since they play a major role as the most effective European powers on the water interaction dynamics in the Nile Basin, in addition to the roles played by Canada and Japan, the two non-European states that play effective roles in financing the water projects in the Nile Basin.

The donors play this role to finance the projects in the Nile Basin believing that the cooperation efforts in developing the Basin can lead to an increase in the water resources which each state uses, in addition to the other advantages like power generation and the cooperation in projects that lead to economic prosperity.

4.4.1 The Italian Role in the Nile Basin

Italy finances developmental projects in the Nile Basin such as: Water Program for Africa and Arid and Water Scarce Zones (WPA) (see the project details in [164]).

The WPA project is concerned with the capacity building of the workers who work in the domain of water resources. The program has a variety of activities including (for more details on the project WPA, see [165]): the achievement of the regional water integrity. As well as the enhancement of the integrated water resources integrity, discovering alternative water resources and the best use of them. The project also includes elevating the medical standards for the citizens through checking the quality of the fresh water resources, helping in strengthening the efforts of the national institutions working in the domain of water. The project also helps in preserving the environment, elevating the quality of surface and groundwater management, enhancing the abilities locally and regionally via training courses on the water resources management. Moreover, it offers the opportunity of arranging seminars and workshops and exchanging of experiences and know-how among the experts in different dry and semi-dry states in the region.

Moreover, on the 2nd of March, 2005, the Italian government announced that it plans to execute a project entitled: "Promoting Equitable and Sustainable use of Nile Water Resources" in cooperation with Food and Agricultural Organization of the United Nations (FAO). The project aims to improve the management of the water resources in the Nile Basin via enhancing the opportunities and domains of obtaining data and information regarding the River resources [166].

In addition to these developmental projects, Italy plays a role in building dams and executing projects in the Nile Basin, especially in Ethiopia. Italy's Ministry of Foreign Affairs presented an aid equal to 150 million USD to contribute to the efforts aiming to solve the famine and migration problems which threaten Ethiopia via the establishment of Beles Dam on Beles River (800 m length, 50 m height), Embogyla Dam (30 m height, 1,100 m length) and a third dam on the small Beles River (200 m length, 40 m height), in addition to executing fresh water stations, groundwater wells, cultivating 100,000 rain water acres and assisting the settlement of 60,000 families [167]. It is worth mentioning that the three dams cannot contain more than 100 million cubic meter/year.

On the 19th of July, 2006, the Ethiopian electrical power authority contracted the Italian company Salini Hostriti to execute Gilgel Gibe dam. It is a project for hydroelectricity generation consisting of three dams that would be built on three phases to convert a part of the river water to Omo River directly after passing through a hydroelectric station (200 MW) in the first phase. This phase has been already executed; the first Gilgel Gibe dam was established in the North of the project in 2004 [168]. Then the most important development was the agreement the Ethiopian government entered with the Salini company to establish the Renaissance Dam (direct governmental order).

The Italian influence can be evaluated as far as the hydropolitics are concerned from two perspectives. The first is positive, since studying the Italian water developmental projects shows that Italy plays an effective role to encourage water cooperation in the Nile Basin. The second is negative since being a donor and an engineering contractor to establish dams in some of the upstream states may cause some disturbances in the water relations among the upstream, middle, and downstream states due to the noncompliance with the prior notification condition when building those dams. This urged Egypt and Sudan to object those projects. Consequently, some conflicting transactions can erupt due to the Italian policies in the Nile Basin.

4.4.2 The Dutch Role in the Nile Basin

Holland is one of the coordinating states of the water cooperation in the Nile Basin, in addition to its effective role in the financial contribution to some of the water projects in Egypt and other Nile states in accordance with "the Nile Basin initiative" or outside it. It cooperates with Egypt by providing scholarships to the Nile states in order to elevate their technical abilities [169].

The water projects executed by Holland include: "the enhancement of participations for users of the integrated management of the water resources." The project aimed to encourage the integrating management of the water resources, achieve an effective partnership among the water sectors in the society, implement the policies related to consumption reduction, protect water from pollution, deepening the general awareness of the water resources cases via general awareness campaigns, conferences and field activities and maximizing the economic, social, and environmental benefits of water [170].

Hence, the above clarifies that the Dutch role is stimulating water cooperation interactions among the Nile Basin states, and may be able to defuse conflicts in the Basin.

4.4.3 The German and Norwegian Role in the Nile Basin

Recently, Germany and Norway were involved in the influencing water transaction in the Nile Basin via their roles as donors and engineering contractors, in addition to their effective roles in financing many water projects and dams in the upstream states. They finance the feasibility studies related to the Kara Dobe dam since 2005 (for more details, see http://www.marefa.org/index.php). It is a dam located on the borders between Amhara and Oromia in Ethiopia. It is a multifunctional dam, one of a set of dams that will be built during the coming few years. Two companies are awarded the pre-feasibility studies and execution (the Norwegian Nor-Plan and the German Lamayour) [171].

4.4.4 The Canadian Role in the Nile Basin

Canada encouraged the dialogues and cooperation among the Nile states urging those states to accept the Nile Initiative in 1999 [172].

Canada managed to contribute efficiently in urging the donors to support the Nile Basin projects. In addition, Canada provides technical and financial aid to assist the execution of the "shared vision projects" which emanated from the "Strategic Action Program" related to the Nile Initiative in many fields such as: the environment, trust building, and energy.

Moreover, it was the most unique donor which formed the International Consortium for Cooperation on the Nile (ICCON) which held its first meeting in Geneva (26–28 June 2001) in response to an invitation by the International bank, to discuss the opportunities and ability to finance the Nile initiative projects.

In October 2001, during the fifth UN conference on the Fight Against Desertification which was held in Geneva (1–12 October 2001), the International Cooperation Minister Mrs. Maria Minna announced that the Canadian International Development Agency (CIDA) will provide 16 million USD as an aid to the Nile Initiative for the purpose of fighting desertification in the Nile Basin (for more details about the Canadian aid, see [173]).

In addition, the agency – in cooperation with other international donors – assisted the Nile states in projects whose scope is to protect the environment, fight poverty and enhancing the regional stability in the Nile Basin.

Based on the above, it is clear that the Canadian role stimulates the water cooperation in the Nile Basin and restrains conflicts.

5 Hydropolitics Scenarios in the Nile Basin

The Hydropolitical relations in the Nile Basin depend on many factors which stimulate conflicts or cooperation [174].

5.1 The Conflicts Scenarios in the Nile Basin

Wu presented an analysis of the water conflicts based on game theory in order to understand the dynamics of the conflicting transactions in international rivers, focusing on the Nile Basin as a case study. He concluded that the new political, climatic, economic, and strategic variables in the region – which was increased in recent years – can increase the possibilities of water conflicts in the Basin [175].

International conflicts and motivational interests may increase the chances of contradiction among the Basin states whether over the water or over other issues while handling the water file. This will remain an undesired scenario from the Egyptian viewpoint.

Therefore, the conflicting tendency related to the Nile Basin states can be escalated in the light of one or more of the following variances:

- The insistence of the upstream countries on the Framework Convention (Entebbe) as a legal framework.
- The construction of dams and water projects in upstream countries without prior notification.
- The Sudanese refusal to the Agreement of 1959.
- The rise of external factor as a catalyst for conflict in the Nile Basin

5.1.1 The Insistence of Upstream Countries on the Framework Convention (Entebbe) as a Legal Framework

The negotiations over the Entebbe Framework Agreement highlighted the historical differences in the visions and expectations of Egypt and Sudan, on the one hand and the upstream states on the other.

Egypt was keen on asserting the "legality" of the former Nile waters agreements since they secure the Egyptian historical and natural rights in the Nile waters. On the other hand, the upstream states were keen on canceling these agreements and refused to recognize them. Likewise, "water sharing" was one of the subjects related to water negotiations and conflicts in the Nile Basin.

The Egyptian official vision was embodied in the disputes that erupted during the negotiations over (Article 14, item B) related to the water security. Egypt completely refused the suggested wording of the mentioned Article because it does not include a recognition to the former historical agreements on the Nile waters [176].

It is expected that in the future the upstream states will insist more on the adherence with this debatable Article (14/B) of the Entebbe Agreement. And it is expected that the dispute will continue in the political visions, with the continued insistence of the upstream countries to adopt the Nile Basin Framework Agreement, especially in the light of the decline in the amount of water resulting from the annual monsoon rains, the speed of evaporation, the change of the rainfall behavior and its change of location and timing, in addition to the increase of the negative influences on the plantation by rain waters and resorting to irrigation using rivers waters; consequently, depending more on the Nile waters [177].

Without reaching a comprehensive legal agreement between the Nile Basin countries, all of the above can cause conflicts in the Nile Basin [178].

5.1.2 Building of Dams and Water Projects in Upstream Countries Without Prior Notification

This condition was an obstacle which hindered reaching a final Agreement among the Nile states. This debate was reflected in the Article 8-B related to the rules and procedures of information exchange regarding the projects and specifications, and the debate over the Article 34-C related to the voting system on the decision. Egypt and Sudan insisted that the decisions must be due to consensus or majority provided that Egypt and Sudan agree. For this reason, the negotiating parties failed to reach an acceptable phrasing regarding the mentioned articles [179].

In parallel, there were negative developments resulting from the Ethiopian declaration regarding the Nile when it announced that it will build a number of dams on the Nile upstream. On the 2nd of April, 2011, the Ethiopian authorities put the milestone of the renaissance Dam to start work, paying no attention to the Egyptian water interests and starting a new era of water conflicts with Egypt [180].

Generally, Ethiopia and the rest of the upstream states tend to adopt the Harmon Theory since it does not limit their absolute handling of the Nile Basin section located within their territories, and in accordance with it they can neglect the principle of prior notification and consultation when they plan to take any steps or implement any regional water developmental projects. In addition, the upstream states adhere to the "exchanging" implementation of the prior notification condition, i.e. they refuse to adhere to it, if the downstream states (Egypt and Sudan) would not be obliged by it similarly. Ethiopia and the upstream states called for this commitment to be bilaterally applicable on both sides (upstream and downstream states).

Consequently, the plans adopted by any upstream state to implement projects or dams in their territories will increase the possibilities of water conflict among the upstream states, on the one hand and the middle and downstream states on the other (for more details on this topic, see [181]).

Hence, the Ethiopian insistence to go ahead with the establishment of Renaissance dam in addition to its carelessness of the Egyptian fears and preoccupations due to the establishment of this dam in accordance with the declared technical specifications by the Ethiopian side will contribute to a tense atmosphere and an increase in the possibilities of water conflicts in the Basin [182].

5.1.3 The Sudanese Refusal of the 1959 Agreement

The separation of Southern Sudan in July 2011 opened the door to worse possibilities of dissection and consequently the collapse of the Sudanese state the "war of all against all."

The dissection of Sudan into statelets on the medium range and the long term consequences constitute direct threats to the Egyptian national security. In addition, the close ties between the Sudan People's Liberation Movement and both of

Ethiopia and the Great Lakes states imply that the hydropolitical situations and orientations of the new state will be in favor of the upstream states which would be a minus in regard to the Egyptian political and negotiation abilities when dealing with them. This appears clearly in the interest of John Garang (formerly) and his predecessor Salva Kiir Mayardit, in the water subject. The Sudan Liberation Movement wished to sell the water as Turkey intends to do. It also had reservations regarding the Egyptian water quota implying that it will not recognize the Agreement of 1959 signed by Egypt and Sudan for it refuses the principle of the "international succession of agreements" (for more details, see [183]). This means that there will be a change to the conflicting transactions by adding a new party refusing the historical agreements and sharing the Nile waters according to the current conditions. This would entail new conflicting interactions over the water in the Nile Basin [184].

5.1.4 The Increase of the External Factors Impacting the Nile Basin

The impact of the external influences in any regional system increases the vulnerability of this system to external penetration [124].

The more the external forces role increase in the Basin, the more there is a conflict of interest among its states. Therefore, it is expected that water conflicts erupt in the Basin with the increase of the political, economic, media, strategic, water, and technical intervention of some regional and international forces. Those forces include Israel, the USA, China, Iran, some Gulf area states, and some international donors (for more details on this topic, see [185]).

The conflicting scenarios increase if any of the external forces entered an alliance with one or more basin states against the interests of one or more states in the Basin.

Applying the power transition theory, we find that all the upstream states – being dissatisfied with the current situation in the Basin and being keen to change them – seek to form external alliances in an attempt to change the status quo and replace it with another situation. They may also seek to make alliances with forces outside the regional system of the Nile Basin through a network of relations with regional and international parties.

The relatively powerful and dissatisfied states in the Nile Basin (Ethiopia, Kenya, Tanzania, Uganda) will not hesitate to escalate the conflict in order to change the status quo in case they have new power sources. In contrast, the relatively weak and dissatisfied states (Democratic Congo, Eritrea, Rwanda, and Burundi) have two alternatives: either to be isolated within the system or seek the satisfaction of the powerful parties that control the system [186]. The powerful parties (dissatisfied as well) seek to form a mutual front to include all the unsatisfied states (strong and weak ones together). In this case, these states will seek to interpret this power conversion into external behaviors with a conflicting nature through the stimulation of unrest, disturbances, and conflicts aiming at changing the status quo to achieve new benefits with the other parties [187].

5.2 *The Cooperation Scenarios in the Nile Basin*

It is estimated that the cooperative tendency regarding the transactions among the Nile Basin states will be increased in the light of one or more of the following variables:

- The execution of collective developmental projects
- The revival and activation of the Nile Basin Initiative (NBI)
- The initiation and activation of the “water diplomacy” between Egypt and the Nile Basin states
- The activation of the people’s diplomacy

5.2.1 The Execution of Collective Developmental Projects

Collective developmental work in the Nile Basin requires a framing of a “mutual developmental work plan” aiming at achieving a mutual development according to the “win–win approach” provided that the collective strategic plan includes a mutual vision regarding the present and future of cooperation and development in the Basin states. In addition, it must include specific tactical and strategic targets that can be evaluated and measures an accurate identification of the implication and work mechanisms according to a specific time schedule with the aim of “creating mutual interests among the peoples of the Basin” leading to vaster domains of cooperation among the Nile states and helps avoid strained relations among them [188].

This can only be achieved through the expansion of mutual developmental work via the establishment of grand developmental projects. It is suggested that projects to make use of the water loss in the equatorial upstream and Bahr el Ghazal area should be implemented rapidly, in addition to the electrical linkage projects which secure mutual benefits among the upstream and downstream states in the Basin [189].

The Nile states have increasing developmental needs due to the population growth, in addition to the fact that they have been classified among the poorest states globally. This situation urges Egypt – due to its scientific, technological, and economic supremacy – to continue supporting those states technically and financially as integrated political deals, especially that all the nine upstream states suffer from poverty and low living standards.

The Human Development Report classified them among the poorest and ranked last in the human development manual [190].

The collective interest in focusing on the establishment of collective developmental projects which guarantee mutual benefits for all the Nile states can increase the opportunities of water cooperation in the future, paving the road for cooperation opportunities in different fields.

5.2.2 The Revival and Activation of the Nile Basin Initiative (NBI)

The Nile Basin Initiative was announced in 1999 as the current cooperative framework in the regional system of the Nile Basin. It relies on the notion of sustainable and unbiased development of the River resources in order to achieve mutual benefits and exchange among all the Nile states according to the "win–win" approach (for more information about NBI, see [191]).

Depending on the optimistic vision tending to adopt the cooperative scenario, it is expected that the potentialities, opportunities, and levels of cooperation in the Nile Basin will be increased in the light of the advantages derived from NBI (for more details about the foundations and principles of the NBI, see [192]).

The initiative was interested in the projects, programs, and mechanisms needed for trust and confidence building among the Nile states. The procedures adopted by the Initiative for building mutual trust helped in the dissipation of doubts and suspicions infecting the relationships in the Nile Basin for a long time.

In addition, the NBI helped in the creation of institutionalization of the collective cooperation. It provided a number of unprecedented institutionalized frameworks and contexts, in comparison with the other cooperative forms. The most prominent frameworks were: the Nile Council of Ministers (Nile COM), Technical Advisory Committee (Nile TAC), and the International Financial Union for Cooperation in the Nile Basin (ICCON) (for more information on the institutional framework of NBI, see [193]).

Undoubtedly, the multiplicity and complexity of the institutional frameworks functionally can strengthen the institutional nature of the initiative, increasing the rates of cooperative interactions in the regional system in the whole Nile Basin [194].

5.2.3 The Initiation and Activation of the "Water Diplomacy" Between Egypt and the Nile Basin States

Water diplomacy is connected to a number of activities, negotiations, and diplomacy aspects which are directed towards a specific water issue in a way that enables the gathering of human efforts and cadres and allocates symbolic and financial capabilities during a specific period of time to achieve objectives on the international water domains, where there is a water strategy, the diplomatic authorities attempt to achieve its objectives via external activities and moves [195].

Water diplomacy is one of the new untraditional diplomacies which prevailed recently regarding the international relations such as: the nuclear diplomacy, the development diplomacy, money diplomacy, oil diplomacy, women diplomacy, and youths diplomacy.

The efficiency of the water diplomacy increases if mingled with untraditional forms of diplomacy, especially the "summit diplomacy," parliamentary diplomacy, and the official and non-official conferences diplomacy [196].

The importance of the water diplomacy when mingled with the summit diplomacy becomes clearer because both provide a much needed force to push the economic, political, security, cultural, water, and technological domains forward. This collective cooperation is the engine pushing towards the enhancement of the collective work, as well as the avoidance of potential spill-backs in some low politics sectors.

Naturally, the Nile states currently may adopt the water diplomacy or, in other words, "the Nile Diplomacy."

Water diplomacy gains its crucial importance in Egypt's foreign policy springing from the special position of the Nile circle to the Egyptian interests. Egypt seeks by water diplomacy in the Nile Basin to maintain the water interests of the Nile Basin states and to activate the cooperation and sustainable and unbiased development of the Nile resources to achieve and exchange mutual benefits among those states according to the "win–win approach" [197].

All fears resulting from the possibility of the conflicting scenarios taking place in the Middle East – generally – over water, and in the Nile Basin – specifically – faded due to the efficiency of the "water diplomacy" plus its effectiveness and its sustainability. Therefore, it is important to stress the fact that water cooperation management is as important as the management of water conflicts. So, Egypt and the rest of the Basin states should use all the ingredients of soft and smart power. This is actually the most needed path to face the current developments in the Nile Basin and maintain the water security for all its states.

5.2.4 The Activation of the People's Diplomacy Among the Nile Basin States

It is very important to activate the "people's diplomacy" whose subject is the people via mass media and from different pulpits depending mainly on the people's non-governmental work [198]. Thus, it applies to: "the activities exerted by a country or a state represented by its people to gain the public opinion away from the embassies' and diplomatic corps' activities or the traditional media of the state's official diplomacy using all its potentialities, relations and communications such as: the international and professional syndicates, students unions, women and youths organizations, parliaments, political parties, athletic teams, folklore groups and similar non-governmental organizations via different human communication mechanisms which develop according to the development of the media and communication mechanisms in the modern age and its relation to what is called the infomedia revolution" [199].

The activation of the people's diplomacy among the Basin states can be implemented via a number of mechanisms including [200]:

- Increasing the student exchange programs between Egypt and other Nile countries, both at the university level, or before the university level, as well as at the level of technical education since the student exchange programs contribute to the creation of new spaces to meet, hold a dialogue and for the understanding of each other, consequently allowing convergence and cooperation.

- Increasing of the exchange of scientific delegations in all scientific disciplines, through scientific conferences and symposia in various domains, as well as mutual work, workshops, and joint training courses among the Nile states to create a dialogue and intellectual, cultural, and civilizational interaction among their intellectual elite. Hence, creating joint research concerns to deal with the societal problems in these countries.
- Increasing of the convergence between the institutions of civil society representatives, political parties leaders and cadres, leaders and members of trade unions, the leaders and members of associations and non-governmental organizations in the Nile Basin states. The compilation of these categories together and the creation of an ongoing and extensive dialogue on various issues of concern to the peoples of the Basin is the necessary condition for cooperation in this area [201].

6 Conclusion

Based on the fact that the objective of the study is analyzing the hydropolitical interactions in the Nile Basin, it is clear that the water conflicts in the region take place in three main domains.

The first is the conflict regarding the "legality" of the historical Nile agreements which were signed in the nineteenth century and during the first half of the twentieth century.

The second is the conflict around the sharing of water in the Nile Basin and the call to the reallocation of quotas and water shares.

The third is the conflict around "the prior notification condition" when executing water projects.

Through the analysis of the official and non-official writings and statements issued by the experts and officials of the Nile Basin states, it was possible to recognize the main broad lines of the political-legal confrontation between the upstream states, on the one hand, and the middle and downstream states (Egypt and Sudan), on the other hand, regarding the former agreements.

As for the upstream states, they refuse the former Nile agreements and demanded they be cancelled due to being signed during the colonization era, and for them to be replaced with new agreements, whereas the middle and downstream states (Egypt and Sudan) assert the legality of those agreements depending on two major principles of the international law which are: the principle of "succession of agreements" as stated by Articles 11 and 12 of Vienna Agreement (1978), and the second principle is the principle of the "historical acquired rights" and the "natural rights" which go back to thousands of years; stressing Egypt's natural rights and its right in the exploitation of the Nile.

The second domain of conflicts in the Nile Basin is the "water sharing."

From one angle, some of the upstream states demanded the reallocation of the water so that the middle and downstream states do not obtain the lion's share of the river. These states suggest certain standards to allocate water.

On the other hand, Egypt and Sudan refuse the reallocation suggestion calling for the adherence of "the equitable utilization" principle since they are the last states on the watercourse and – according to the Agreement of 1959 – they exploit what reaches them. Plus, the rains falling on their territories are much less than those falling on the upstream area.

With the turn of the century, some of the upstream states demanded that the water be considered an "economic good" that will be sold to Egypt and Sudan and get a price in exchange for what they get. On the other side of the hydropolitical interaction, Egypt and Sudan refuse this idea and consequently refuse to sell the water internationally.

There are indications that the conflict over the water sharing will remain one of the highlighted subjects in the future in relation to the hydropolitical relations in the Nile Basin.

The "prior notification condition" was the third domain for conflicts in the Nile Basin. Both Egypt and Sudan insist on this condition to be respected in all the water projects on the Nile since it is an authentic principle of the international law which is the principle "not to cause harm to other states."

In contrast, the Nile upstream states insist on the noncompliance with the prior notification condition due to their conviction that adherence to this condition imposes a limitation on their freedom and a derogation of their sovereignty, as well as hindering their developmental projects.

Moreover, the Israeli role in the Nile Basin depends on two strategies. The "quotation," i.e. obtaining a stable quota of the Nile waters and besieging the Arab and Egyptian policies in the Nile region through a network of relations and water, political and economic penetration in the Nile states. Hence, the Israeli role in the Basin stimulates conflicts.

As for the US role, it focuses on the geostrategic importance of the Nile Basin in relation to the US interests and objectives. The USA seeks to besiege and dwarf the Egyptian regional role and empower the Ethiopian and Israeli roles in the region to assist the US political and strategic hegemony in the region.

The US policy in the Nile Basin depends on two strategies: the AFRICOM which is the American African Command and the strategy of the African Great Horn. Therefore the US role in the area encourages water conflicts.

China and Italy played an important role in influencing the hydropolitical interactions in the Nile Basin through providing financial, technical, and technological support to a number of water projects and dams in the area. The evaluation of the Chinese and Italian roles showed that there are two contradicting views regarding those roles: a positive view by the upstream states and a negative view by Egypt and Sudan because the latter see that the Chinese and Italian contractors do not comply with the prior notification condition before the implementation of water projects in the Basin.

There were also some international donors such as Holland, Germany, Norway, Japan, and Canada who provided financial, technical, and engineering aid in addition to financing the suggested cooperative water projects in the framework of the Nile Basin. The increase of the international donors helped to defuse conflicts and stimulated cooperation in the area.

Depending on reading the scenarios of the hydropolitical relations in the Nile Basin, the analysis clarified that the conflicting interactions will be increased in the area due to one or more of the following variables: the insistence of the upstream states on the Entebbe Framework Agreement as a legal framework, the execution of dams and projects in the Nile upstream states without prior consultation, the refusal of the Republic of South Sudan to the Agreement signed by Egypt and Sudan in 1959 and the increased external interventions that stimulated conflict.

On the other hand, it is anticipated that the cooperative tendency regarding interactions among the Nile Basin states will increase due to one or more of the following variables: the establishment of collective developmental projects, the resurrection and activation of the Nile Basin Initiative, the activation of water diplomacy between Egypt and the Nile Basin states and the activation of the people's diplomacy.

To conclude, the weighting scenario remains subject to the will of the people and the states of the Nile Basin, depending also on the rational choice and the trade-offs between the alternatives: managing the conflicts or managing the cooperation on water in a promising area.

References

1. Waterbury J (1979) Hydropolitics of the Nile valley. Syracuse University Press, Syracuse, pp xii, 39–45, 301
2. Abdul Ghani M (1985) Saudi, Sudan. Egyptian Anglo library, Cairo (in Arabic)
3. Tesfaye A (2014) Conflict and cooperation and the evolution of the Nascent Nile basin regime. Northeast African Studies 14(1):123–144
4. Jacobs I (2006) The water war debate: swimming upstream or downstream in the Okavango and the Nile? University of Stellenbosch, Stellenbosch; Tadesse D (2012) Is a war over the Nile imminent? Institute for Security Studies, Cape Town. www.issafrica.org; Nile dam: water wars averted for now (2012) Financial Times, 19 June 2012. http://www.ft.com/cms/s/0/1f820ab2-b608-11e1-a511-00144feabdc0.html#axzz24mAeU79P
5. Vella J (2012) The future of food and water security in new Egypt. Strategic Analysis Paper, 22 Nov 2012
6. Deconinck S (2009) Security as a threat to development: the geopolitics of water scarcity in the Nile River basin. Royal High Institute for Defense, Brussels, 13 Dec 2009, pp 2–7, Published as a Focus Paper
7. Tayie MS (2013) Analytical vision of the indicators of the Egyptian water security. Int Politics 191:58–63 (in Arabic); Tayie MS (2013) National and regional water security policies in the Gulf states. In: Tayie MS et al (eds) Water and food security in the Arabian Gulf. The Emirates Center for Strategic Studies and Research, Abu Dhabi, pp 103–133
8. Morrissette JJ (2007) The myth of water wars: a hydropolitical economy of conflict and cooperation. PhD thesis, Georgia, pp 147–168; Turton A (2002) Hydropolitics: the concept

and its limitations. In: Turton A, Henwood R (eds) Hydropolitics in the developing world: a southern African perspective. African Water Issues Research Unit (AWIRU), Centre for International Political Studies (CIPS), University of Pretoria, Pretoria, pp 13–20; Dinar S (2000) Negotiations and international relations: a framework for hydropolitics. Int Negot 5 (2):375–400; Turton A (2002) Expanding the hydropolitics concept: towards a new research agenda for Southern Africa. In: Turton A, Henwood R (eds) Hydropolitics in the developing world: a southern African perspective. African Water Issues Research Unit (AWIRU), Centre for International Political Studies (CIPS), University of Pretoria, Pretoria, pp 239–247

9. Waterbury J (1979) Hydropolitics of the Nile valley. Syracuse University Press, Syracuse, pp xii, 301
10. Molinga PP (2008) Water policy-water politics social engineering and strategic action in water sector reform. Water Politics and Development Cooperation, Part 1, pp 1–29. http://www.ahewar.org/debat/show.art.asp?aid=161976
11. Michel D, Pandya A (eds) (2009) Climate change, hydropolitics, and transboundary resources. Henry L. Stimson Center, Washington; Elhance AP (2000) Hydropolitics in the third world: conflict and cooperation in international river basins. Int Aff 76(2):369–370. http://www.jstor.org/stable/2626399
12. Towfique B, Espey M (2002) Hydro-politics: socio-economic analysis of international water treaties. Paper submitted to American Agricultural Economics Association, 15 May 2002, pp 3–6
13. Wolf AT (1995) Hydropolitics along the Jordan River: scarce water and its impact on the Arab-Israeli conflict. United Nations University Press, Tokyo
14. Ohlsson L (ed) (1995) Hydropolitics: conflict over water as development constraint. University Press Ltd, London and New Jersey
15. Allan TA (2002) The middle east water question: hydropolitics and the global economy. I.B. Tauris, London and New York
16. Turton A, Meissner R. Hydro polities in the developing word: a southern African perspective. www.iwmi.cgiar.org/.../River%20basin%20management%20reconsidered%WESTER.pdf. Accessed 25 Dec 2010
17. Ifabiyi IP (2013) Recharging the Lake Chad: the hydropolitics of National Security and Regional Integration in Africa. Afr Res Rev 7(3):196–216, Serial No. 30; Sinaei V (2011) Hydropolitics and human security: water cooperation in relations between Iran, Afghanistan and Turkmenistan. Iran Rev Foreign Aff 2(3):111–134; Zambrano Ramirez JP (2012) Red hot hydropolitics: human and state security implications of water scarcity in Chile. Master thesis, School of Social and Political Sciences, University of Melbourne, pp 34–40
18. Frederiksen HD (2009) The world water crisis and international security. Middle East Policy 16(4):76–88
19. Anthony T, Roland H (eds) (2002) Hydropolitics in development world: a southern African perspective. African Water Issues Research Unit (AWIRU), Pretoria, pp 7–10
20. Wolf AT (1996) Hydrostrategic territory in the Jordan basin: water, war and Arab-Israeli peace negotiations. University of Alabama, Department of Geography, Tuscaloosa; Wolf AT (2000) Hydrostrategic territory in the Jordan basin: water, war and Arab – Israeli peace negotiations. In: Amery AA, Wolf AT (eds) Water in the middle east: a geography of peace. University of Texas Press, Austin
21. Allan T (2002) The middle east water question: hydropolitics and the global economy. Arab Stud J 9/10(2/1):160–164. http://www.jstor.org/stable/27933822; Turton A, Henwood R (eds) (2002) Hydropolitics in the developing world: a southern African perspective. African Water Issues Research Unit (AWIRU), Centre for International Political Studies (CIPS), University of Pretoria, Pretoria, pp 11–13
22. Allan JA, Mallat C (eds) (1995) Water in the middle east: legal, political and commercial implications. British Academy Press, London; Burleson E (2006) Middle Eastern and North African hydropolitics: from eddies of indecision to emerging international law. Georgetown Int Environ Law Rev 18:386. http://digitalcommons.pace.edu/lawfaculty

23. Woodhouse M, Zeitoun M (2008) Hydro-hegemony and International water law: grappling with the gaps of power and law. Water Policy 10(Suppl 2):103–119; Cascão AE, Zeitoun M (2010) Power, hegemony and critical hydropolitics. In: Earle A, Jägerskog A, Ojendal J (eds) Transboundary water management: principles and practice. Earthscan, London, pp 27–42
24. Zeitoun M, Warner J (2006) Hydro-hegemony – a framework for analysis of trans-boundary water conflicts. Water Policy 8(5):435–460; Daoudy M (2008) Hydro-hegemony and international law: laying claims to water rights. Water Policy 10(2):89–102; Winslett G (2015) Substitutability, securitization and hydro-hegemony: ontological and strategic sequencing in shared river relations. Confl Secur Dev 15(3):283–309; Turton AR (1999) Water and state sovereignty: the hydropolitical challenge for states in arid regions. Water Issues Study Group. www.soas.ac.uk
25. Wu X (2000) Game-theoretical approaches to water conflicts in international river basins: a case study of the Nile basin. PhD thesis, University of North Carolina at Chapel Hill, pp 25–26, 125–127; Yoffe S, Wolf AT, Giordano M (2003) Conflict and cooperation over international freshwater resources: indicators of basins at risk. J Am Water Resour Assoc 39 (5):1109–1126; Pittman K (2004) Beyond conflict and cooperation: hydropolitics in the Nile basin. MA thesis, Concordia University, Montreal. http://search.proquest.com/docview/305133339?accountid=27191
26. Swain A (1997) Ethiopia, the Sudan, and Egypt: the Nile River dispute. J Mod Afr Stud 35 (4):675–694
27. Fadel YA (1999) The problem of the Nile Basin water distribution: the reality and the future. Unpublished Master thesis, University of Algiers, pp 92–93, 131 (in Arabic)
28. Abu Zeid M (1998) The water source of tension in the 21st century. Al-Ahram Center for Translation and Publishing, Cairo, pp 159–160 (in Arabic); Allam MNE (2001) Water and agricultural land in Egypt: past, present and future. Academic Library, Cairo, pp 73–75 (in Arabic); Waterbury J (1987) National sovereignty and step towards super national management of water. Paper presented in the international symposium of the Nile basin, Institute of African Studies, Cairo University, Cairo, pp 22–23; Dellapenna J (1994) Treaties as instruments for managing international – shared water resources: restricted sovereignty vs. community of property. J Int Law 26:27–33; Collins RO (2000) In search of the Nile waters, 1900–2000. In Erlich H, Gershoni I (eds) The Nile: histories, cultures, myths. Lynne Rienner, Boulder, pp 245–267
29. Dellapenna JW (2002) The Nile as a legal and political structure. In: Caste Lein S, Otte A (eds) Conflict and cooperation related to international water resources: historical perspective. Technical documents in hydrology, vol. 62. UNESCO, Paris, pp 35–47, 39
30. Hassanein FA (1997) The water and the political game cards in the middle east. Madbouly Library, Cairo, pp 73–74 (in Arabic)
31. Hecht E-D (1987) Ethiopia threatens to block the Nile. Paper presented to the symposium on the Nile basin, Institute of African Studies, Cairo, p 30
32. Abdul Salam HA (1967) The state of the second Mamluks. Dar Al Arab Book, Cairo, p 161 (in Arabic)
33. Shukri MF (1958) Egypt and Sudan: history of political unity of Nile Valley in the nineteenth century 1820–1899 (in Arabic). Dar El-Maarif, Cairo, p 423; Mohamed HA, Sharif AA (2000) A historical study of the Egypt's water policy and the position of the international and local powers including 1929-1959. PhD thesis, Institute of African Research and Studies, Cairo University, pp 257–259 (in Arabic)
34. Hurst HE, Phillips P (1938) The Nile basin. Ministry of Public Works and Water Resources and Schindler's Press, Cairo
35. Al-Tamimi AEK (1999) Arab water: challenge and response. Center for Arab Unity Studies, Beirut, p 160 (in Arabic)
36. People Assembly, The Committee of Arab Affairs (2004), A report on "Egyptian strategy to keep the waters of the Nile". Parliament, Cairo, pp 9–11 (in Arabic); Abate Z (1990) The integrated development of Nile basin waters. In: Howell, Allan JA (eds) The Nile. A conference organized

by the Royal Geographical Society and the School of Oriental and African Studies, University of London, 2–3 May 1990, pp 143–144; Arsano Y (2004) Ethiopia and the Nile: dilemma of national and regional hydro-politics. PhD thesis, Center for Security Studies, Swiss Federal Institute of Technology, Zurich

37. Fadel YA (1999) The problem of the Nile Basin water distribution: the reality and the future. Unpublished Master thesis, University of Algiers, pp 85–87; Tafesse T (2001) The hydropolitical assessment of the Nile question: an Ethiopian perspective. Water Int 26(4):578–588
38. Abdel Razek A (2004) The hotbeds of tension and conflict over water in the Nile, the Arab world and the strategic Egyptian water policy in the basin of the Nile basin: analytical and legal study in the framework of international political relations. Egyptian General Book Authority, Cairo, p 61 (in Arabic); El-Rubaie S (2001) Water conflict and the crisis rights between the Nile basin countries. Dar al-Kalima, Damascus, p 129 (in Arabic)
39. Tilahun W (1979) Egypt's imperial aspirations over lake of Tara and the Blue Nile. United Printers Ltd, Addis Ababa, p 61
40. Mohsen AA (1980) Egypt, Ethiopia: clash over nil. Middle East 71:70; Ferede W, Abebe S (2014) The efficacy of water treaties in the Eastern Nile basin. Afr Spectr 49(1):55–67
41. Al Abdullah H (1992) Arab water security. Center for Strategic Studies and Research and Documentation, Beirut, p 103 (in Arabic); Turton AR (2000) A cryptic hydropolitical history of the Nile basin for students of hydropolitics. Study Guide for Pretoria University, Pretoria, pp 11–12
42. El-Rubaie S (2001) Water conflict and the crisis rights between the Nile basin countries. Dar al-Kalima, Damascus, pp 101–102, 119
43. Elhadidy A (1991) The Egyptian foreign policy towards the Nile. Int Politics 104:124 (in Arabic)
44. Turton AR (2000) A cryptic hydropolitical history of the Nile Basin for students of hydropolitics. Study Guide for Pretoria University, Pretoria
45. Okidi CO (1980) Legal and policy regime of Lake Victoria and Nile basins. Indian J Int Law 20:16–24; Godfrey Okoth P (2007) The Nile river question and the riparian states: contextualizing Uganda's foreign policy interests. Afr Sociol Rev 11(1):81–94
46. Rashidi A (1993) Border disputes in international law: its causes and ways of peaceful settlement. In: Abdel-Alwanees Shata A (ed) The international borders of Egypt. Center for Political Research and Studies, Cairo, pp 217–219 (in Arabic)
47. Connel DPO (1956) The law of state succession. Cambridge University Press, Cambridge, pp 15–16
48. Rashidi A (1993) Border disputes in international law: its causes and ways of peaceful settlement. In: Abdel-Alwanees Shata A (ed) The international borders of Egypt. Center for Political Research and Studies, Cairo, p 218; Brownlie I (1979) Principle of public international law. Oxford University Press, Oxford, p 667
49. Mahdi MA (1996) Political boundaries and the reality of the state in Africa. African Center for Future Studies, Cairo, pp 192–193 (in Arabic)
50. Mahdi MA (1996) Political borders and territorial integrity of the African state. Master thesis, African Research and Studies Institute, Cairo University, pp 177–203 (in Arabic)
51. Rashidi A (1993) The southern border of Egypt. In: Abdel-Alwanees Shata A (ed) The international borders of Egypt. Center for Political Research and Studies, Cairo, p 456; Mahdi MA (1996) Political borders and territorial integrity of the African state. Master thesis, African Research and Studies Institute, Cairo University, pp 193–194; Chie S (1969) The Organization of African Unity and African Boundaries. In: Widstrand CC (ed) African boundary. The Scandinavian Institute of African Studies, Uppsala, pp 87–89
52. Interview with Prof. Salah Eldin Ammer, a professor of international law at Cairo University, 15 Jan 2005; Awda AE (1997) The difficult situation in the countries of the Nile. Al-Ahram (in Arabic)
53. UN convention on the Law of the Non-navigational Uses of International Watercourses. http://internationalwaterlaw.org/documents/intldocs/watercourse_conv.html
54. Vienna convention on succession of states in respect of treaties (1978) Vienna, 23 Aug 1978

55. Abu Zeid M (2004) Egypt and the southern states in the Nile region. Al-Ahram Elmasaai, 20 Mar 2004 (in Arabic)
56. Abdel-Rahman M (1991) The law of the use of international rivers in the non-navigational affairs. Arab Renaissance Publishing House, Cairo, pp 231–232 (in Arabic)
57. Rashidi HA (2014) Acquired rights in international law: theoretical study with the application on the rights of Egypt's Nile water. Dar Al Nahda Al Arabia, Cairo, pp 707–710 (in Arabic)
58. El-Far AW (1999) Historical and legal rights of Egypt in the waters of the Nile. In: Mansour MI (ed) Arab water and the challenges of the twentieth century. Future Studies Center at Assiut University, Asyut, pp 167–177 (in Arabic)
59. El Tawab A, El Hai A (1988) The Nile and the future: what happened to the Nile and its tropical and Ethiopian sources. Al-Ahram Center for Translation and Publishing, Cairo, p 158 (in Arabic)
60. Abdel-Hadi Radi M (1989) Water and peace: Ethiopian floating icebergs. J Water Sci 25:19–20 (in Arabic)
61. Griffin WL (1959) The use of water of international drainage basins under customary international law. Am J Int Law 53:61–67
62. International Law Association (2001) The Helsinki rules on the uses of the water of international rives. International Law Association, London. http://www.Intrantionalwaterlaw.org/IntlDocs/Helsinki-Rules.htm. Accessed 18 June 2001
63. Caponera DA (1985) Patterns of cooperation in international water law: principles and institutions. Natl Resour J 25:563–588
64. UN convention on the law of the non-navigational uses of international watercourses. http://internationalwaterlaw.org/documents/intldocs/watercourse_conv.html; Cano G (1989) The development of the law in international water resource and the work of the international commission. Water Int 14:167–171
65. Küng R (2003) Addressing the dimensions of transboundary water use: the Nile basin initiative. Mt Res Dev 23(1):4–6; Moon S (2012) Strife on the Nile: the battle for water rights. Harv Int Rev 34(2):8–9
66. Swain A (2011) Challenges for water sharing in the Nile basin: changing geo-politics and changing climate, Hydrol Sci J 56(4):687–702; Ahmad S (1994) Principles and precedents in international law governing the sharing of Nile waters. In: Howell PP, Allan JA (eds) The Nile: sharing a scarce resource: a historical and technical review of water management and of economical and legal issues. Cambridge University Press, Cambridge, pp 351–363; Beyene Z (2004) A quest for distributive justice in the Nile basin. Int J Ethiop Stud 1(2):16–39
67. Interview with Prof. Diaa Eldin El Qosi, a consultant at the Ministry of Water Resources and Irrigation, Cairo, 3 Oct 2004; Abu Zeid M (1998) The water source of tension in the 21st century. Al-Ahram Center for Translation and Publishing, Cairo, pp 159–162; Cascão AE (2009) Political economy of water resources management and allocation in the eastern Nile river basin. PhD dissertation, Department of Geography, King's College London
68. ElQosi DE (2004) No for negotiating on Egypt's share of water. Al Ahram Al Arabi, No. 378, 19 June 2004; The Standard (2007) Egypt, Sudan against equitable sharing of Nile water. The Standard (Kenya), 29 June 2007; El Zain M (2007) Environmental security, hydropolitics, and the Nile: population concentration, water scarcity and the changing domestic and foreign politics of Sudan. PhD thesis, Institute of Social Studies, The Hauge
69. Attfy HE (2002) Assessment of water resources in the Nile basin countries for sustainable development. PhD thesis, Institute of African Studies and Research, Cairo University (in Arabic); Stastone BK (1959) The utilization of the Nile water. Int Comp Law Q 8:550–560; Pugh D (1990) Egypt: next war could be over water quotas from the Nile. The Guardian, 12 Oct 1990, p 33; Kendie D (1999) Egypt and the hydro-politics of the Blue Nile river. Northeast Afr Stud, New Series 6(1/2):141–169
70. Aamer SE (2004) Water rights and distributive justice at the international level. A lecture delivered at the workshop on water rights and distributive justice, Cairo, 18 Sept 2004

71. Wachtel HM (2007) Water conflicts and international water markets. In: Shuval H, Dweik H (eds) Water resources in the middle east Israel-Palestinian water issues: from conflict to cooperation. Springer, Berlin Heidelberg, pp 147–153
72. Luzi S (2007) Double-edged hydropolitics on the Nile linkages between domestic water policy making and transboundary conflict and cooperation. PhD thesis, Swiss Federal Institute of Technology, Zurich, pp 73–85
73. Keith B, James Enos MAJ, Garlick CB, Simmons G, Copeland D, Cortizo M (2013) Limits to population growth and water resource adequacy in the Nile river basin, 1994-2100. Center for Nation Reconstruction and Capacity Development, US Military Academy, New York, pp 1–7
74. Al-Mansour AAS (2000) The water issue in Syrian policy toward Turkey. Center for Arab Unity Studies, Beirut, pp 161–163 (in Arabic); Calabi H, Majzoub T (1995) Turkey: the waters of the Euphrates and public international law. In: Allan JA, Mallat C (eds) Water in the middle east: legal, political and commercial implications. Library of Modern Middle East Studies and I.B. Tauris, London and New York. Distributed by: St. Martin's Press, 1995, pp 201–209
75. Hassan HA, Al Rasheedy A (2007) The Nile river and Egyptian foreign policy interests. Afr Sociol Rev 11(1):25–37; Kendie D (1999) Egypt and the hydro-politics of the Blue Nile river. Northeast Afr Stud 6(1–2):141–169. http://muse.jhu.edu/journals/nas/summary/v006/6.1kendie.html
76. Lewis MW (2013) Egyptian protests, Ethiopian dams, and the hydropolitics of the Nile basin. http://geocurrents.info/environmental-geography/egyptian-protests-ethiopian-dams-and-the-hydropolitics-of-the-nile-basin
77. Eltahry H (1998) The future of water in the Arab world. Cairo, p 21 (in Arabic)
78. An interview with Mahmoud Abu Zeid, former Minister of Water Resources and Irrigation, Cairo, 7 Feb 2005
79. An interview with Mohamed Nasreddin Allam, the former Minister of Water Resources and Irrigation, Cairo, 8 Sept 2015
80. Waterbury J, Whittington D (1998) Playing chicken on the Nile? The implications of micro dam development in the Ethiopian highlands and Egypt's new valley project. Nat Resour Forum 22(3):155–163
81. When interviewed by the researcher, the Ethiopian officials asserted this meaning including: Shiver Ogarso, Ethiopian Minister of Water Resources, Tefera Binet, head of design of dams and hydropower department, the Ethiopian Ministry of Water Resources, Mousa Mohammed Obsino, President of the International Water Division, the Ethiopian Ministry of Water Resources, 17 Feb 2005
82. Pankhurst R (1997) Ethiopia's alleged ability to control the Nile in medieval times. Paper presented to the international conference on the Nile: civilization, history, myths, Tel Aviv University, Tel Aviv, 19–22 May 1997; Putrick G (1990) Recent history of Ethiopia. In: Davidson (ed), Africa South of the Sahara. Europe Publications, UK, pp 458–462
83. Marcus H (1983) Ethiopia, Great Britain and the USA: 1941–1974. University of California Press, Berkeley, pp 103–104
84. Interview with Boutros-Ghali, the former UN Secretary General, and the former Minister of State for Foreign Affairs, Cairo, 25 June 2005 and July 2013
85. Bolloch J, Darwish A (1993) Water wars: coming conflicts in the middle east. Cassell, London and Oxford, p 130
86. Salman AI (1988) Ethiopia's socialist transformation. Int Politics 91:234 (in Arabic); Clapham C (1987) Revolutionary, socialist development in Ethiopia. J Afr Aff 86(343):151–159
87. Hashem YA (1991) Political, economic and legal dimensions of the water crisis. Int Politics 104:152 (in Arabic)
88. Bleier R (1997) Will Nile water go to Israel? North Sinai pipelines and the politics of scarcity. Middle East Policy 7(3):113–124
89. Hecht E-D (1987) Ethiopia threatens to block the Nile. Paper presented to the symposium on the Nile basin, Institute of African Studies, Cairo, pp 2–3, 30

90. Awda AM (1996) The permanent interests of the Egyptian state. Al-Ahram Newspaper, 15 June 1996 (in Arabic); Waterbury J (1996) River Nile: do the upper Nile states challenge the current status quo. Al Hayat, 27, 28, and 29 June 1996
91. Awda AM (1996) The issue of water: is the confrontation began? Al-Hayat, Aug 1996 (in Arabic)
92. Tayie MS (2010) Water projects in the Nile basin: analytical vision of hydropolitical perspective. In: Egyptian conditions, vol. 47. Center for Political and Strategic Studies in Al-Ahram, Cairo (in Arabic); Patel S (2009) Ethiopia completes construction of Africa's tallest dam. Power News, 1 July 2009; Hydro to drive development: Ethiopia discovers its most valuable resource. Hydropower Report, May 2006
93. Al-Hayat newspaper. London, 7 April 1998
94. Tayie MS (2014) Renaissance dam and its impact on Egypt's water security: a study of geopolitics perspective. In: Tayie MS et al (eds) The issue of Nile water. Faculty of Arts, Cairo University, Cairo, pp 213–286 (in Arabic); Veilleux JC (2013) The human security dimensions of dam development: the Grand Ethiopian Renaissance Dam. Glob Dialogue 15 (2):1–13; Batisha AF (2015) Sustainability assessment in transboundary context: Grand Ethiopian Renaissance Dam. Springer, Cham, pp 1–36
95. Hagos T. Ethiopia and the sovereignty over the Blue Nile [Online]. http://www.ethiomedia.com/13report/5194.html. Accessed 5 Nov 2013
96. Arsano Y (2007) Ethiopia and the Nile: dilemmas of national and regional hydropolitics. PhD thesis, Center for Security Studies, Swiss Federal Institute of Technology, Zurich, pp 58–62
97. Akwei BA (2015) Hydropolitics, hydro-hegemony and the problem of Egypt's securitization of the Eastern Nile basin. PhD theses, Howard University. http://search.proquest.com/docview/1712398719?accountid=27191
98. Map of Ethiopia's 4 new dams on Nile (2001) Horn Affairs, 1 July 2001. http://hornaffairs.com/en/2011/07/01/leaked-map-of-ethiopias-4-new-dams-on-nile/
99. Paisley RK, Henshaw TW (2013) Transboundary governance of the Nile river basin: past, present and future. Environ Dev 7:59–71
100. Cascão AE (2008) Ethiopia challenges to Egyptian hegemony in the Nile basin. Water Policy 10(2):13–28; Saleh SMK (2008) Hydro-hegemony in the Nile basin: a Sudanese perspective. Water Policy 10(Suppl 2):29–49
101. Africa Report (2012) Ethiopia's dams bring rebirth and power to East Africa. http://www.theafricareport.com/20121102501820994/east-hornafrica/ethiopias-dams-bring-rebirth-and-power-to-east-africa-501820994.html. Accessed 8 Feb 2014
102. Beyene A (2013) Why is the hydroelectric dam on the Blue Nile, the Grand Ethiopian Renaissance Dam (GERD), sized for 6000 MW? http://gadaa.com. Accessed 19 June 2013
103. Beyene A (2013) Ethiopia's biggest dam oversized, experts say. International Rivers, 5 Sept 2013
104. Allam MNE (2001) Water and agricultural land in Egypt: past, present and future. Academic Library, Cairo, pp 85–86
105. Allam MN (2014) The Ethiopian Renaissance Dam crisis: a political issue or a technical problem. Al Mahrousa Center for Publishing, Cairo, pp 139–151 (in Arabic); Shteiwi MA (2016) Principles of international law governing the construction of dams on international rivers: an empirical study on the Ethiopian Renaissance Dam. Dar Nile for Publishing and Printing and Distribution, Cairo, pp 107–120
106. Yihdego Z (2013) The Blue Nile dam controversy in the eyes of international law. Global Water Forum: Part 1 [Online]. http://www.globalwaterforum.org/2013/06/18/the-blue-nile-dam-controversy-in-the-eyes-of-international-law/. Accessed 5 Nov 2013
107. Gobre-Sellassie Z (1997) The Nile question 1955-1964 the Ethiopian perspective. Paper presented to the conference on the Nile: civilization, history, myths, Tel Aviv University, Tel Aviv, 19–22 May 1997

108. Marcus HG (1997) A resource impossible to exploit: Ethiopia and the geopolitics of lake Tana. Paper presented to the conference on the Nile: civilization, history, myths, Tel Aviv University, Tel Aviv, 19–22 May 1997
109. Bach H, Bird J, Clausen TJ, Jensen KM, Lange RB, Taylor R, Viriyasakultorn V, Wolf A (2012) Transboundary river basin management: addressing water, energy and food security. Mekong River Commission, Vientiane, Lao PDR
110. Scheumann W, Neubert S (eds) (2006) Transboundary water management in Africa: challenges for development cooperation. German Development Institute (DIE), Bonn
111. Tadessea S, Milesib J-P, Deschampsb Y (2003) Geology and mineral potential of Ethiopia: a note on geology and mineral map of Ethiopia. J Afr Earth Sci 36(4):273–313
112. Awulachew SB, McCartney M, Ibrahim Y, Shiferaw YS (2008) Evaluation of water availability and allocation in the Blue Nile basin. CGIAR challenge program on: water and food 2nd international forum on water and food, Ethiopia, pp 6–10
113. Cascão AE (2009) Changing power relations in the Nile river basin: unilateralism vs. cooperation? Water Alternatives 2(2):245–268; Rahman MA (2012) Water security: Ethiopia–Egypt transboundary challenges over the Nile river basin. J Asian Afr Stud 48 (1):35–46; Cascao A, Zeitoon M (2010) Changing nature of bargaining power in the hydropolitical relations in the Nile River Basin. In: Earle A, Jägerskog A, Ojendal J (eds) Transboundary water management: principles and practice. Earthscan, London, pp 189–194
114. Hanke N (2013) East Africa's growing power: challenging Egypt's hydropolitical position on the Nile? Master thesis, Faculty of Political Science at Stellenbosch University, pp 20–27; Kindie D. Egypt and the hydro-politics of the Blue Nile river. http://chora.virtualave.net/kendie-nile.htm. Accessed 5 Nov 2013
115. Swain A (2011) Challenges for water sharing in the Nile basin: changing geo-politics and changing climate. Hydrol Sci J 56(4):687–702
116. Schadomsky L. Egypt and Ethiopia argue over dam project. http://www.dw.de/egypt-and-ethiopia-argue-over-dam-project/a-16880722. Accessed 14 June 2013
117. Martens AJ (2011) Impacts of global change on the Nile basin options for hydropolitical reform in Egypt and Ethiopia. International Food Policy Research Institute (IFPRI), Discussion Paper 01052, Jan 2011, pp 12–17
118. Allan JA (2009) Nile basin asymmetries: a closed fresh water resource, soil water potential, the political economy and Nile transboundary hydropolitics. Nile Monograph Biological 89:749–770; Martens AJ (2011) Impacts of global change on the Nile basin options for hydropolitical reform in Egypt and Ethiopia. International Food Policy Research Institute (IFPRI), Discussion Paper 01052, Jan 2011, pp 6–20
119. Abu Atta AA et al (1985) The Nile river: past, present and future. Dar Al Arab Future, Cairo, p 112 (in Arabic)
120. Burchi S, Sperij M (2003) Institutions for international freshwater management. Technical Documents in Hydrology, PCCP Series No. 3. UNESCO, Paris, pp 12–14; Godana BA (1985) Africa's shared water resources: legal and institutional aspects of the Nile. Niger and Senegal River Systems, Graduate Institute of International Studies, Geneva
121. Wahab AA (2002) Globalization and the cooperation of water in the Nile basin. Int Politics 150:54–55 (in Arabic)
122. Nile Water Sector. A report on "The current situation of the Nile basin countries and the challenges facing Egypt in the development of water resources". Nile Water Sector, Cairo, p 5 (in Arabic)
123. Presidency, Specialized National Councils, The National Council for Agricultural Production (1990) A report on "The natural and historical rights of Egypt in the Nile water and associated agreements. Specialized National Councils, Cairo, p 19 (in Arabic)
124. Cantori LJ, Spiegel SL (1970) The international politics of regions: a comparative approach. Prentice-Hall, Englewood Cliffs, pp 9–22, 25–30
125. Idris MS (2001) Regional systems analysis: the study of the origins of international and regional relations. Center for Political and Strategic Studies in Al-Ahram, Cairo, pp 73–74

(in Arabic); Cantori LJ, Spiegel SL (1970) The international politics of regions: a comparative approach. Prentice-Hall, Englewood Cliffs, p 1
126. Azar EE, Moon C-I (1988) Rethinking third world national security. In: Azar EE, Moon C-I (eds), National security in the third world: the management of internal and external threats. Center for International Development and Conflict Management, University of Maryland, College Park, pp 1–13
127. Wriggins WH (1992) Conclusion. In: Wriggins WH et al (eds) Dynamics of regional politics: four systems on the Indian Ocean Rim. Columbia University Press, New York, pp 291–297
128. Fadel YA (1999) The problem of the Nile Basin water distribution: the reality and the future. Unpublished Master thesis, University of Algiers, pp 92–93
129. Abu Zeid M (1998) The water source of tension in the 21st century. Al-Ahram Center for Translation and Publishing, Cairo, p 145
130. Abdel-Rahman H (2001) US policy toward Africa from isolation to partnership. Int Politics 144:196 (in Arabic); U.S. Foreign Policy on Water Resources in the Middle East: Institute for Peace and Development, Conference, (CSIS), Washington, 23 Nov 1988
131. Word PW (1996) The horn of Africa: politics and international relations. Jamis Academic Studies, London and New York, pp 135–152; Nenze PB (1991) The horn of Africa from war to peace. Macmillan, Hong Kong, pp 39–64
132. Khattab NM (1986) Israel knocks the doors new Africa. Arab Aff 47:174–180 (in Arabic)
133. El Tayyar KI (1986) Israel's attempts to return to Africa and its relationship with the convention on the strategic cooperation with the United States. Arab Aff 47:169–171 (in Arabic)
134. Starr JR, Stoll DC (eds) (1989) The politics of scarcity: water in the middle east. West View Press, Boulder, pp 3–5, 127
135. Abdel-Rahman H (2001) US policy toward Africa from isolation to partnership. Int Politics 144:196
136. Bakr H (1993) Water wars in the middle east from the Euphrates to the Nile. Int Politics 111:75–77 (in Arabic)
137. Lawson L (2007) U.S. Africa policy since the cold war. Strategic Insights 6(1). http://www.ccc.nps.navy.mil/si/2007/Jan/lawsonJan07.asp
138. Otto Sieber CDR (2007) Africa command: forecast for the future. Strategic Insights 6(1). http://www.ccc.nps.navy.mil/si/2007/Jan/sieberJan07.asp
139. Volman D (2003/2004) The Bush administration and African oil: the security implications of U.S. energy policy. African Security Research Project, ACAS Bull 66:15–25. http://acas.prairienet.org/pubs.html
140. Foster JB (2006) A warning to Africa: the new U.S. imperial grand strategy. Monthly Review, June 2006. http://www.monthlyreview.org/0606jbf.htm
141. Seib P, Weil C (2008) AFRICOM, the American Military and Public Diplomacy in Africa. USC Annenberg, Policy Briefing, Mar 2008
142. AFRICOM: the militarization of U.S. diplomacy and foreign aid (2008) Policy Brief, June 2008. www.transafricaforum.org
143. The Greater Horn Horizon Forum (GHHF) (2010) http://www.greater-horn-horizon.org/
144. Serchuk V (2007) Ethiopia versus the Islamists. Weekly Standard 12(17):8–15
145. Lyons T (2006) Ethiopia in 2005: the beginning of transition. Center for Strategic and International Studies, Africa Notes, No. 25, Jan 2006
146. Lyons T (2006) Avoiding conflict in the horn of Africa: U.S. policy toward Ethiopia and Eritrea. Center for Preventive Action, Council on Foreign Relations, CSR No. 21, Dec 2006
147. Global Water Security: Intelligence Community Assessment, ICA 2012-08, 2 Feb 2012
148. Al-Momani M (1986) Water policy of the Zionist entity: a study in political geography. Dar Ammar Publishing and Distribution, Amman (in Arabic); Zahreddine S (1996) Greater Israel project: between demography: oil and water. Arab Center for Research and Documentation, Beirut, pp 133–162 (in Arabic); Byrine A (1994) Water. Jerusalem Media and Communication Center (JMCC), Jerusalem

149. Riyadh M (1985) Israel and the Arab water in historical perspective. In: Farid AM, Sirriyeh H (eds) Israel and Arab water. Oxford Press, London; Tamimi A (1991) Water: a factor for conflict or peace in the middle east. Paper submitted to Arab Studies Society and Truman Research for the Advancement of Peace, Rome; Zoubi A (1992) The Jewish invasion of the Arab water: a Torah Dream and sustainable work. Dar Valuables, Beirut, 1992, pp 13–15 (in Arabic); Barghouti B (1986) Israeli ambitions in Palestine water. Dar Galilee Publishing, Oman, pp 140–145 (in Arabic)
150. Rayes CN (1986) The water problem in Israel and its impact. Nasser Military Academy, National Defense College, Cairo, p 4 (in Arabic)
151. Herzl T (1968) Diary Herzl (trans: Sayegh HS). Research Center, Beirut (in Arabic); Demashqiah G (1993) The water crisis and conflict in the Arab region. Dar Elahaly, Damascus, p 89 (in Arabic); Deevic U (1980) Antonia Max and John Wilson and Tichlrd, water policy for Israel. Institute for Palestine Studies, Beirut (in Arabic)
152. Schmida LC (1984) The implications of Israeli water policy for the Arab-Israeli conflict. Yarmouk University, Irbid; Davis O (1984) Arab water recourse and Israel water policy. Yarmouk University, Irbid, pp 16–17
153. Saadawi AAK (1999) The Nile river in the Israeli strategy. In: Mansour MI (ed) Arab water and the challenges of the twentieth century. Future Studies Center at Assiut University, Asyut, p 710 (in Arabic); Abdullah SEH (2004) Zionist ambitions in the waters of the Nile. J Crim Soc Sci 8. Research for criminal and social studies. National Rabat University, Khartoum, pp 352–353 (in Arabic); Kally E (1991) Water and peace: Israeli point of view (trans: Haidar R). Institute for Palestine Studies, Beirut (in Arabic)
154. Bleier R (1997) Will Nile water go to Israel? North Sinai Pipelines and the politics of scarcity. Middle East Policy 5(3):113–124; Kally E (1974) Extension of Israel's National Water System as a function of artificial rainfall. Water Resources Research Publications, The American Biophysical Union; Kally E, Fishelson G (1993) Water and peace: water resources and the Arab-Israeli peace process. Praeger, London and Westport
155. Decalo S (1998) Israel and Africa: forty years (1956-1996). Florida Academy Press, Gainesville and London, pp 13–22
156. Choukri (1990) The Israeli-Ethiopian cooperation and national security of Egypt. Int Politics 101:175 (in Arabic); Kaplan S (1997) Did Jewish influences reach Ethiopia via the Nile? Paper presented to the international conference on the Nile: civilization, history, myths, Tel Aviv University, Tel Aviv, 19–22 May 1997; Ojo OS (1988) Africa and Israel: relations in perspective. West View Press, London and Boulder, pp 45–46, 147; Swain A (1997) Ethiopia, the Sudan and Egypt: the Nile river dispute. J Mod Afr Stud 35(4):675–694
157. Zrnoqh SS (2000) Israeli penetration in Africa and its impact on Arab national security. In: Nasreddin I et al (eds) Arabs and Africa in the post-cold war. Development – Issue, No. 18. Center for the Study and Research of Developing Countries, Cairo, pp 98–102 (in Arabic); Al Zoghbi HAK (1985) The Zionist penetration risks in Africa. Kazma Company, Kuwait, pp 18–1 (in Arabic); Abdul Rahman H (2001) Israel and Africa in a changing world: from penetration to hegemony. A series of Egyptian-African Studies, No. 3. Egyptian African Studies Program at Cairo University, Cairo, p 2 (in Arabic); Kamel O (1998) Israeli penetration proportions in Africa. The Defense Magazine, Cairo, Mar 1998, p 18 (in Arabic); Qureshi R (1996) Nile basin, Ethiopia, Israel: critical triangle in the Arab water security. An Arab Economic Research, No. 5. Arab Association for Economic Research, pp 160–162 (in Arabic); Bard MG (1988–1989) The evolution of Israel's Africa policy. Middle East Review, pp 20–23
158. Matkees H, Arafa K (eds) (2006) The rise of China. Cairo, Center for Asian Studies
159. Li A (2007) On changes and adjustments in China's policy toward Africa. Zhongguo Weijiao, China's foreign policy, No. 1, pp 33–40
160. Yu GT (2009) China, Africa, and globalization: the "China alternative". ASIA PAPER, Institute for Security and Development Policy, June 2009

161. Yu GT (1988) Africa in Chinese foreign policy. Asian Survey 28(8):849–862. http://www.jstor.org/stable/2644590; Yu GT (1975) China's African policy: a study of Tanzania. Praeger, New York
162. Tayie MS (2010) Water projects in the Nile basin: analytical vision of hydropolitical perspective. In: Egyptian conditions, vol. 47. Center for Political and Strategic Studies in Al-Ahram, Cairo; Thakur M (2009) Building on progress? Chinese engagement in Ethiopia. Occasional Paper 38. South African Institute of International Affairs (SAIIA). http://www.saiia.org.za/images/stories/pubs/occasional_papers/saia_sop_38_thakur_20090723_en.pdf? Accessed 10 May 2010
163. Emerging Chinese Communities in Africa (2008) The China Monitor, No. 26, Feb 2008; International Rivers (2012) China's global role in dam building. http://www.internationalrivers.org/campaigns/china-s-global-role-in-dam-building; Adar KG (2007) The interface between national interest and regional stability: the Nile river and the riparian states. Afr Sociol Rev 11(1):4–9
164. Italian Ministry for the Environment and Territory (2005) Water programme for Africa, arid and water scarce zones 2004-2006. Ministry for the Environment and Territory, Italy
165. Ministry for the Environment and Territory (Italy), UNESCO-IHP. Water program for Africa: arid and water scarce zones 2004-2006. http://www.minambiente.it. Accessed 5 Mar 2011
166. Italy funds Nile basin water management project. http://www.panapress.com/newslatf.asp?code=eng074531&dte=04/03/2005. Accessed 31 Feb 2011
167. Pankhurst R (1997) Ethiopia's alleged ability to control the Nile in medieval times. Paper presented to the international conference on the Nile: civilization, history, myths, Tel Aviv University, Tel Aviv, 19–22 May 1997
168. Ethiopia – Gilgel Gibe dam unites Ethiopians. www.nazret.com
169. Ministry of Foreign Affairs, Policy and Operations Evaluation Department (1998) Sub-report on: "Egypt evaluation of the Netherlands support to water management and drainage 1975-1996". Policy and Operation Department, Ministry of Foreign Affairs, The Hague, pp 87–131
170. Egyptian water partnership magazine (2002) 2nd edn (in Arabic)
171. Ethiopia to build 800-million-dollar dam (2005) http://english.people.com.cn/200509/28/eng20050928_211309.html
172. An interview with Mahmoud Abu Zeid, former Minister of Water Resources and Irrigation, 7 Feb 2005
173. Canada helps Africa combat desertification in the Nile basin (2001) http://www.acdicida.gc/ca/cida.ind.nsf/0/8978888d9eca191085286ae10055710f?openDocument
174. Bittman K (2004) Beyond conflict and cooperation: hydropolitics in the Nile basin. Master thesis, Concordia University, Montreal, pp 43–60
175. Wu X (2000) Game-theoretical approaches to water conflicts in international river basins: a case study of the Nile basin. PhD thesis, University of North Carolina; Howe L. Hydropolitics of the Nile river: conflict, policy, and the future. http://www.hamilton.edu/documents/levitt-center/Howe_article.pdf May 2010
176. Tadesse D (2007) The Nile as a source of cooperation or conflict: the case of Ethiopia, Egypt, and the Sudan. In: Kitissou M, Ndulo M, Nagel M, Grieco M (eds), The hydropolitics of Africa: a contemporary challenge. Cambridge Scholars Publishing, Cambridge, pp 19–50; Abawari YM (2011) Conflict and cooperation among the Nile basin countries with special emphasis on the Nile Basin Initiative (NBI). Master thesis, The Hague, pp 14–17
177. Yitayew M, Melesse AM (2011) Critical water resources issues in the Nile river basin. In: Melesse AM (ed) Nile river basin hydrology, climate and water use. Springer, Dordrecht, pp 408–411
178. Kimenyi MS, Mbaku JM (2015) Governing the Nile river basin: the search for a new legal regime. Brookings Institution Press, pp 1–146. http://www.jstor.org/stable/10.7864/j.ctt130h973
179. Tayie MS (2008) The negotiating position of the headwaters of the Nile basin countries to the framework convention, 5th edn. The African Strategic Report 2007/2008. African Research

Center, Cairo (in Arabic); Ibrahim AM (2011) The Nile basin cooperative framework agreement the beginning of the end of Egyptian hydro-political hegemony. Missouri Environ Law Policy Rev 18(2):283–313; Abawari YM (2011) Conflict and cooperation among the Nile basin countries with special emphasis on the Nile Basin Initiative (NBI). Master thesis, The Hague, pp 14–17

180. Rahman MA (2012) Water security: Ethiopia–Egypt transboundary challenges over the Nile river basin. J Asian Afr Stud 48(1):35–46
181. Tayie MS (2010) Water projects in the Nile basin: analytical vision of hydropolitical perspective. In: Egyptian conditions, vol. 47. Center for Political and Strategic Studies in Al-Ahram, Cairo; Waterbury J, Whittington D (1998) Playing chicken on the Nile? The implications of micro dam development in the Ethiopian highlands and Egypt's new valley project. Nat Resour Forum 22(3):155–163; Yohannes O, Yohannes K (2012) Turmoil in the Nile river basin: back to the future? J Asian Afr Stud 48(2):195–208
182. Allam MN (2014) The Ethiopian Renaissance Dam crisis: a political issue or a technical problem. Al Mahrousa Center for Publishing, Cairo, pp 123–151; Obengo JO (2016) Hydropolitics of the Nile: the case of Ethiopia and Egypt. Afr Secur Rev 25(1):95–103
183. Tayie MS (2010) The impact of the secession of southern Sudan on Nile water crisis. In: Abu-Eyenin M et al (eds) The Egyptian-Sudanese relations in the light of the current conditions in Sudan. Institute for African Research and Studies, Cairo, pp 259–286 (in Arabic); Salman SMA (2011) The new state of South Sudan and the hydro-politics of the Nile basin. Water Int 36(2):154–166
184. Kenyi UGF (2011) Water security and hydropolitics of the Nile river: South Sudan's National Security in the 21st century. Master thesis, Faculty of the U.S. Army Command and General Staff College, pp 73–76
185. Tayie MS (2009) The impact of external interventions on water relations in the Nile basin. Awraq Elsharq Alawsat. National Center for Middle East Studies, No. 46, Cairo (in Arabic); Kehl JR (2011) Hydropolitical complexes and asymmetrical power: conflict, cooperation, and governance of international river systems. J World Syst Res 17(1):218; Tesfaye A (2006) Hydropolitics and regional stability in the Nile basin. aigaforum.com/articles/Hydropolitic_in_the_NileBasin.pdf. Accessed 16 Aug 2006
186. Organski AFK (1968) World politics. Alfred Knopf, New York, pp 293–295; Kugler J, Organski AFK (1989) The power transition: a retrospective and prospective evaluation. In: Handbook of war studies. Unwin Hyman, Boston; Lemke D (1997) The continuation of history: power transition theory and the end of the cold war. J Peace Res 34(1):23–36. http://www.jstor.org/stable/424828
187. Cascão AE (2009) Changing power relations in the Nile river basin: unilateralism vs. cooperation? Water Alternatives 2(2):245–268
188. Morbach M, Ribbe L, Pedroso R (2014) Supporting the development of efficient and effective river basin organizations in Africa: what steps can be taken to improve transboundary water cooperation between the Riparian States of the Nile? In: Nile river basin: ecohydrological challenges, climate change and hydropolitics. Springer, Cham, pp 597–636; Khalid M (1981) The Nile waters: the case for an integrated approaches. In: Beshir M (ed) The Nile valley countries: continuity and change, vol. 1. Institute of African and Asian Studies, University of Khartoum, Khartoum, p 12
189. Mason SA (2004) From conflict to cooperation in the Nile basin. ETH Zurich, Zurich; Allan JA (1996) The Nile basin: water management strategies and development policies for harmonized Nile waters development and management. In: The Nile: sharing a scarce resource. Cambridge University Press, Cambridge, pp 299–301, 385–393; Whittington D, McClelland E (1992) Opportunities for regional and international cooperation in the Nile basin. Water Int 17(3):144–154
190. United Nations Development Programme (2015) Work for human development. Human Development Report 2015, Washington. http://hdr.undp.org

191. El Khodari NM (2005) CEO, Nile basin society, Canada. Paper presented at international conference of basin organizations, Madrid, 4–6 Nov 2002. file:\water\the Nile Basin Initiative (NBIS): Business as usual.htm. Accessed 28 Feb 2005
192. Nile Basin Initiative (Nelsap) (2005) Strategic/sectoral, social and environmental assessment of power development options in the Nile equatorial lakes region, stage II, energy policies and legal and administrative frameworks; Grey D (2005) Global and African water challenges, and Nile water perspectives. Current Cooperation and Future Opportunities for Joint Development, Eastern Nile; Foulds KE (2002) The Nile basin initiative: challenges to implementation. Paper presented to the managing shared water conference, Ontario, 23–28 June 2002. File:\water\ the Nile Basin Initiative Challenges to Imptemeutation.htm. Accessed 28 Feb 2005
193. Nile Basin Initiative (2001) Nile Basin initiative secretarial, taking the strategic action program. International Consortium for Cooperation on the Nile (ICCON), 24 May 2001; Council of Ministers of Water Affairs of the Nile Basin States Nile Basin Initiative (2001) The (Nile – SEC). Entebbe, Uganda
194. Abawari YM (2011) Conflict and cooperation among the Nile basin countries with special emphasis on the Nile Basin Initiative (NBI). Master thesis, The Hague, pp 29–33
195. Priscoli JD, Wolf AT (2009) Water wars, water reality: reframing the debate on transboundary water disputes, hydropolitics, and preventive hydrodiplomacy. In: Managing and transforming water conflicts. Cambridge University Press, Cambridge, pp 9–32. doi:10.1017/CBO9780511551536.005
196. Zeitouna M, Warnerb J, Mirumachic N, Matthewsd N, McLaughline K, Woodhousef M, Cascãog A, Allan TJA (2014) Transboundary water justice: a combined reading of literature on critical transboundary water interaction and 'justice', for analysis and diplomacy. Water Policy 16:174–193
197. Williams P (2002) Nile co-operation through hydro-realpolitik? Third World Q 23(6):1189–1196
198. Dubayan MH (2007) Public diplomacy. The Diplomat, The Institute of Diplomatic Studies of the Ministry of Foreign Affairs, Kingdom of Saudi Arabia, No. 34, pp 58–61 (in Arabic)
199. van Ham P (2005) Power, public diplomacy, and the Pax Americana. In: Melissen J (ed) The new public diplomacy soft power in international relations. Antony Rowe Ltd, Chippenham and Eastbourne, pp 49–58
200. Tayie MS (2009) The role of national forums in the Nile Basin Initiative. Int Politics 44(175) (in Arabic); Cull NJ (ed) (2009) Public diplomacy: lessons from the past. Figueroa Press, Los Angeles. www.uscpublicdiplomacy.org
201. Mason SA (2005) Are we scorpions? The role of upstream-downstream dialogue in fostering cooperation in the Nile basin. Mt Res Dev 25(2):115–120

The Legal Aspects of the International Rivers: The Nile River as a Case Study

Mohamed Salman Tayie

Abstract International laws concerning rivers has remained in the shadows until recently. Consequently, there have been a limited number of agreements that organize maritime regulation in international rivers. Yet, in the light of technological and scientific progress, onshore states' interest did not focus only on navigation in mutual international rivers but also on other uses such as power generation, fishing, establishment of dams, and diversion of river streams.

Such an issue raises many questions regarding the rights of every state amongst the other onshore states, as far as international rivers are concerned, and the mutual obligations among them. If each state possesses equal rights, then how would the benefits of the river be evenly distributed? What are the obligations that restrict the riverine states in comparison to other states regarding the usage? To what extent is each state responsible internationally regarding the defects resulting from this usage? To what extent are states keen to cooperate, consult, and notify others regarding future projects? Is there a sole riparian state that has the priority to use the river more than the others? And to wh3at extent are the specific legal rules developed to solve any water disputes in a peaceful manner?

The River Nile is an explicit example. Although there are over ten Nile water agreements, they are either bilateral or trilateral agreements. Hence, there is no all-inclusive agreement between the countries of the Nile Basin. Therefore, the absence of an organizing legal framework can increase the potential international conflicts among the Nile Basin states.

This study is based on the legal analytical methods in analyzing the legal dimensions of international rivers on the Nile River. This aim is achieved through covering the following points: regulations of the uses of the international rivers, and

M.S. Tayie (✉)
Political Science Department, Faculty of Economics and Political Science, Cairo University, Giza, Egypt
e-mail: msalman@feps.edu.eg

A.M. Negm (ed.), *The Nile River*,
Hdb Env Chem (2017) 56: 655–716, DOI 10.1007/698_2016_111,

consequently the rights of riparian states, the No-Harm Rule, the principle of equitable and reasonable utilization, and legal status of the Nile River.

Keywords Equitable and reasonable utilization, Harmon theory, Historic acquired right, International treaties succession, No-Harm Rule, Prior notification condition, Significant harm, Theory of absolute integrity of the river, Theory of absolute territorial sovereignty, Theory of common interest, Water sharing

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1 Introduction

The international law related to the international rivers has remained in the shadows until recent years since the international rivers and their usage did not reach the appropriate level of interest until the turn of the nineteenth and twentieth century. Hence, an international regulation was required. Therefore, at that time, there were a limited number of agreements that dealt with the maritime regulation in the international rivers.

Yet, in the light of the noticeable technological and scientific progress, onshore states interest did not focus only on navigation in the mutual international rivers but also on the other uses such as power generation, fishing, establishments of dams and projects related to agricultural areas avoiding the surplus water being discharged into the seas through storing it behind dams, diverting river streams, fighting pollution, and protection of the environment [1].

Those usages became closely associated with the standard rates of the population lives, the development of social and economic programs, and – consequently – the cultural and human development programs, resulting in a positive impact on the stability of the states located in the basin of the international river [2].

This multiplicity and the abundance of the activities related to it led to more rarity of freshwater in spite of the fact that many states hosting international rivers are keener to conclude international agreements over this subject. Yet, this did not cease the eligibility for international conflicts around the rights in water resources [3]. Some of those states even cut the diplomatic ties and threatened to take military actions (Bolivia has cut off diplomatic relations with Chile due to the conflict, "Loki" river "Lauce," and also-Pakistani Indian dispute over the Indus river water, and the conflict between Israel and some Arab countries on the Jordan River, and what is happening now between the Nile Basin countries, especially between Ethiopia and Egypt. See [4]).

The issue raised many questions regarding the nature and the extent of rights possessed by the onshore states as far as international rivers are concerned, and the mutual obligations among them. If each possesses equal rights to those of the others, how can the benefits of the rivers are distributed evenly? And what are the obligations that restrict the riverine states when facing other states regarding the usage of each state share? What are the commitments a state bears regarding the usage of the international river in the light of the well-meaning principle? To what extent the state is responsible internationally regarding the defects resulting from this usage? To what extent the states are keen to cooperate, consult, and notify others regarding the future projects? Is there any specific activity – irrigation or power generation, for instance – that should be prioritized over others? Is there a sole riparian state enjoying the priority to use the river, more than the others?

For instance, can it be said that Egypt – depending mainly on the river Nile since the dawn of history – enjoys rights that are more sublime or exceeds the rights of other riparian states due to the fact that it is considered – historically – the first consumer of this water because its economy and the life of its people depend – almost completely – on it, or not? [5].

To what extent it can be said that there are specific legal rules which can be relied upon to resolve disputes in this domain peacefully, guarantee the minimum level of good neighboring, and maintain the legitimate rights of each riparian state to benefit from the international river resources.

One of the most developing factors that became related to the law of international rivers is the consideration that the water stream – in spite of running throughout many states – is undividable unique natural unit, so managing it should be via mutual cooperation and understanding [6].

River Nile is an explicit example; it embraces many factors that ignite dispute among the states that host it. It also embraces many other elements that can be the base for cooperation and benefits maximization. The Nile is the longest river worldwide, running in the lands of 11 states with a considerable range of varieties and different levels of reliance on the water of the river. It is – for some – the main source of water – and life – such as Egypt, where 95% of its citizens depend on the Nile, recently and historically. Hence came Herodotus say: “Egypt is the gift of the Nile,” and is the gift of many other states, as those located at by source – not suffering from water shortage, on the contrary enjoying abundant rain. The states on the river banks do not share a common agreement regarding t its waters. The Nile may be the only grand international river that lacks any international agreement to regulate the usage of its water by those states in spite of the fact that there are bilateral and multilateral agreements governing some sides of those relations, but those agreements are not collective.

It is well acknowledged that there is no sole collective legal framework which governs – clearly – different procedural aspects and organizes the hydro-legal affairs of the Nile Basin, since it is considered one of the regional regimes. Therefore, the absence of an organizing legal framework and the lack of an accepted system aiming at regulating the Nile Basin system can increase the possibilities of international conflicts among the Nile Basin states.

In addition, there are political interventions and pressures practiced by foreign countries (not located in the Nile Basin) in order to stimulate disputes and disagreements to paralyze the potential cooperation opportunities in order to achieve political adjectives [7].

This study depends on analyzing the legal dimensions of the international rivers with an application of the river Nile via approaching the following analytical points:

- Regulations of the Uses of International Rivers
- Theories of the Riparian States’ Rights
- The No-Harm Rule
- The principle of Equitable and Reasonable Utilization
- Legal status of the Nile River

2 Regulations of the Uses of International Rivers

It can be said that there are some principles regulating the utilization of the international rivers which were considered by the international law maker as due respect principles including “respecting previous agreements”, acknowledging the right of each state to receive the same amount of water which it was previously receiving, the principle of “the even and fair distribution of the river water”, the principle of "not causing substantial harm to the other riparian states", the principle of obliging the states seeking to adjust the water utilization rates via the establishments of dams or streams diversion, to enter negotiations with other states regarding these plans or provide them with a "prior notification" at the least, the principle of "cooperation among the riverine states", "protect the river environment and maintain it" and the principle of "mutual management of the international river waters" which is the most recent principle among others [8].

If gaining the utmost and best benefits is the objective which onshore states should seek, this does not necessarily mean that this is the most effective usage technologically and economically. It does not also mean that the state which possesses the capability to adopt these effective ways will have the strongest claims regarding the utilization of the water. Actually, it will mean seeking the utmost possible benefits for the favor of all the onshore states, on one hand, and reducing the damages they suffer as a result of the variety of uses carried on by others to the minimum level, on the other hand [9].

Yet, this useful or harmful exploitation often leads to conflicts amongst the river basin states as a result of the different interests and the emergence of the exploitation. Hence, there is a need to have clear and stable legal basics to govern the utilization of the international rivers and regulate the related dispute [10].

The present implies that there are numerous differences circulating around each international river as far as circumstances, status, and considerations are concerned, since each river illustrates a unique example even with the existence of some similarities with others. Therefore, it is logical that there are no unified international legal rules which can be applied on all international rivers at the same time, but general rules from which the beneficiaries take what matches their interests and omitting which they see unfit.

Naturally, disputes emerged due to the special interests of the states in the water regardless of the negative results which have a damaging impact on the onshore states.

In this context, there were initiations aiming at concluding agreements that can regulate the rule of using the international rivers, stating the special rules and systems related to this concept to regulate "the method of sharing the water in an attempt to maintain," "acquired and legitimate rights."

For this reason, a quest emerged regarding the essence of the international legal rules governing the utilization of the international rivers [11].

Although there are 261 international common rivers around the world (International rivers are defined as the rivers that are located in the territory of more than one country or that separates the borders between countries. For more details about the statistics on the number of international river basins, see [12]), the complicated and varied aggressive and peaceful relations among those states stimulated international law makers to innovate legal rules and regulations to constitute a framework in organizing and regulating these relations.

There are four factors that the international community should be put into consideration when developing the international law of rivers [13]:

1. There are no regional agreements organizing the relationships amongst the states located on the banks of those rivers stating their quotas of water and obliging them to cooperate in specific frameworks, with the exception of 58 basins around the world. This means that most of the international basins are not covered by agreements (About 80% of the total international river basins suffer from a lack of legal frameworks for the organization of their affairs. And still the Nile Basin falls into this category. See [14]).
2. As a result of not having extensive agreements in the basins of the international rivers and the absence of regional entities to regulate the relations amongst them, there is an absence of institutions and foundations that monitor the agreed terms and prevent conflicts that may erupt as well as no present solutions to those that erupted already.
3. The terms of the international law related to rivers are relative, i.e., the legal rules which format these laws do not apply on the entire international river in the same way. Privacy and relativity are two main features of the international rivers law due to the hydraulic, geographical, topographical, and morphological aspects, in addition to the political, social, and economic considerations related to each basin solely.
4. There is no international specialized identity which is designed to deal with the problems of freshwater and assist in managing them in a better way.

In the light of the above, we can identify a definition for the international law related to the international rivers as follows: "the legal international terms which govern the different uses of the international rivers water, the international waterways and the riparian basins" [11].

This law relates the private and public international agreements, the international customs, the general principles of the law, the judicial verdicts, the international jurisprudence and the writings of senior jurists (for more details about the legal system for the use of international rivers in the Non-Navigational Uses, see [15]).

This urged the General Assemble of the United Nations to intervene via the International Law Commission to form firm international terms to organize the way of managing the waterways usage as far as non-navigational matters are concerned [16].

The International Law Commission's efforts culminated in the preparation of the UN Convention on the Law of the Non-Navigational Uses of International Watercourse in May 1997 [17].

The ratification of this convention culminates the considerable efforts exerted by the International Law Commission, more than a quarter of a century was needed to reach the draft of this convention needed [18, 19].

Perhaps the most important feature that distinguishes the law of waterways usage in non-navigational purposes (ratified by UN on the 21st May, 1997) that it is a framework convention. This means that this convention states a mere general framework including a set of major of principles and core provisions that are related with the non-navigational usage of river water (Supporters believe that there is already a common feature in the waterways that can be drawn from some of the principles of international law applicable, such as good neighborliness and non-abuse of the right, and goodwill, this would represent a minimum to protect the rights and interests of the riparian states in the absence of special agreements between them. See [19]).

Then came the special conventions ratified by a group of riparian states that consume its water mutually. The starting points of those conventions are the general terms and the holistic assets mentioned in the framework convention, with the consideration of the special status of the river under all circumstances (see the concept of the Framework Agreement [20]).

Each river enjoys a unique geographic, political, and social identity which obstructs the notion that unified international rules can govern all rivers in the light of this variety [21].

Honestly, there are a set of general legal rules which organize the exploitation of the international rivers. Those rules emerged in the context of the international customs then were maintained in the international conventions and in the courts' rulings, this can be summarized as follows [22]:

2.1 *Equality between riverine states* in the right of each of them in the exploitation of the river water in the territory of a free hand and unilaterally.

> Equality principle – in this context – means that each state owns equal rights regarding the usage of the river water similar to those enjoyed by other states. Yet, this equality does not mean – intuitively – that every state can obtain the same usage and benefits quota similar to other states, with the water being arithmetically distributed among them equally. It means – only – that each state has the right to use the waterway fairly even if other states are obtaining a larger quota. The extent of the fair usage rights depends on natural, historical, and economic factors which can be different from one state to the other [23].

2.2 *The obligation of each state to respect that of other states* can use the river which runs in its grounds and refrain from practicing any kind of exploitation that may harm the rights of others.

> In this context, two major and integrated international legal principles are underlined. The first is to refrain from abusing the rights; meaning that the state does not use its absolute sovereignty to execute projects that may harm the interests of other onshore states. The second is the principle of good faith in international relations. Meaning that the state should not execute absurd projects on the waterway to harm others on purpose or with the aim to gain fewer benefits regardless of the harm other will suffer from.

2.3 *Protection of the acquired historical rights* (the acquired historical rights of the old and stable legal theory, which in its origin dates back to the Roman law, and can be found in many branches of the law, especially the civil law and the private international law. See for more details [24]): the historical rights to a state is its right to obtain a certain amount or water and always use it according to former and stable distribution procedures as long as the circumstances and status remain the same [23]. According to this rule, the onshore states are obliged to respect the historical rights of each other, with the same amount and annual quota which it is accustomed to have along the previous years since its population settled on the banks of the river.

The logical and legal justification of this rule depends on the fact that the citizens have become adapted to a certain lifestyle connected to the river. Hence, any plus or minus change in the water amounts or specifications may lead to discrepancies and may, consequently, constitute a threat to the international peace and security, especially if there were other available alternatives. The "historical rights" or historical usage depends on an important principle which claims that the status that remained at use for a long time should not be amended on a large scale. That was the principle which was stressed by the permanent court that ruled in the dispute between Sweden and Norway (1909): "It is prescribed in the people's act of principles that the state of the list of things for a long time should not be changed as much as possible." [25].

Frequent exploitation for long periods of time without objection from the downstream countries creates acquired rights that should be protected. Hence, history becomes one component of this right via considering the method the onshore states use to share the water along centuries. In other words, in reference to the contemporary international rivers law, the acquired right, or the former usage means that the first who uses the water of the river has a legitimate right in it, putting it priority before others according to the principle "first-come, first served" or "first in time, first right."

Actually, this principle – named also the "prior usage" or "prior appropriation" – is a crucial principle in the domain of the contemporary law for international rivers. It is one of the special criterions in the domain of the non-navigational usage to the international rivers due to it being a major criterion of equitable and Reasonable utilization guaranteeing and maintaining the relations among the onshore states.

The principle of equal rights was one of the subjects highlighted by the international law commission when drafting the UN convention on the law of international rivers during the discussions regarding how states should inherit the treaties (according to a memorandum of the Secretariat of the United Nations to the International Law Commission to mark the start of international succession in 1948 that the principle of acquired rights from the prescribed principles is considered exploitation status of the benefits of, it may not be intact but with their consent. See [26]).

Although there is a strong opposition in the contemporary international law to indorse the notion of the acquired rights as a whole because it violates the newly liberated states, on the one hand, and does not meet the principle of equality, on the other, yet it is important to assure that the law is still recognizing the acquired rights which are guaranteed – without objection – for a long period of time and are followed by all legal implications and consequences.

In its ruling on the 10th September, 1923 regarding some issues connected to a number of German colonies located in areas which Germany has surrendered to Poland, the International Justice Court expressed its content regarding the historical rights that are derived from treaties and conventions as the acquired rights does not cease to be effective in cases of sovereignty change. And its ruling regarding the Oscar Chinn (1934), the court saw that Britain, when taking actions to confront Oscar Chinn – resulting in halting his business – violated the general principles of the international law especially regarding the principle of the acquired rights. This also occurred when in the Norwegian Traps case (1951) [27].

2.4 *Equitable and Reasonable Utilization* in sharing water justly and evenly.

It is one of the principles of the contemporary international law on rivers and one of the most important criteria regarding sharing the waters of the international waterways. It refers to the states achieving the utmost benefit and meeting the utmost needs, as well as mitigating the harm. Considerable attention should be paid to the fact that Equitable and Reasonable Utilization share does not necessarily mean arithmetic equality among all the states that share the international river, since each state has the right to Equitable and Reasonable Utilization share designed in accordance with its needs and in the light of the historical, geographical, and economic circumstances of each state. If some jurists called for the complete application of the principle of equality among the states regarding the distribution of quotas, the majority adopts the principle of the just and logical distribution in accordance with the needs of each state relying on fixed bases such as the size of the cultivated and cultivable areas of the territory, the population and the extent to which there are alternatives of river water. States tended to apply the principle of Equitable and Reasonable Utilization distribution as adopted by the International Justice Court and other international arbitration courts (more details, see [28]).

2.5 *Obligation to consult when implementing private river projects*, pursuant to the principle of good neighborliness, which stipulates that the state keeps the interests of other states and consult with them regarding the projects that it plans to make on the banks of the river located inside its territory, which would affect their rights or interests.

The decisions of international bodies and the scientific committees determined the way and means of the settlement of disputes by peaceful means in the event of disagreement between the downstream countries as a result of the execution of such projects [29].

2.6 *Good-well usage or using the water in a way not to harm other states* means that no state has a right to execute any engineering or architectural works which may lead to harming the rest of the onshore states.

According to the good-well principle, it is also obliged to refrain from the execution of any works which aim at diverting the stream and change its course or obstruct navigation along it. In accordance with the same principle, onshore states should refrain from using the section of the river – running through its territories – in a way that may cause harm to other states. If this harm is done, the doer should bear the international responsibility and pay the enough compensation for the removal of this harm. A limited number of the international conventions took the concept of "absolute harm" into consideration [30] For example, the British-Italian protocol (signed on 15 April 1891) stated that Italy is obliged not to execute any engineering or architectural establishments on the Atbara River in "Habasha" (today's Ethiopia) which may negatively affect the water flow into the Nile. Similarly, there was an agreement on the 11th of January, 1909 between Britain and the USA stating "each party should not pollute the water in any way that may harm the heath or the properties in the territories belonging to the other party." In addition to the Norwegian – Finish agreement on the 14th February, 1925 regarding Pasvik River, in which the first and second Articles of the agreement stressed that all parties should not take any step to amend the waterway system of the river, in a way that may cause harm to the other state. Also, the agreement between Austria and Czechoslovakian Prague on the 12th of January, 1928 obliged the parties' signatory that neither of them should take any procedures that may affect the hydrosystem inside the territories of the other state. There were also correspondences between Egypt and UK regarding the River Nile on the 16th of July, 1952 and January, 1953 referring to the importance of avoidance any "harm" that may affect the Egyptian interests. Moreover, on the 27th of September, 1971, Peru signed an agreement with Ecuador stating in its first Article that each part acknowledges the right of the other party in using the water running through its territories "providing that the other party will not be harmed" [31].

However, the majority of the texts in question dealt with prevention of the harm that affects the vital interests of the state regardless of the variety of the definitions of the dame, either substantial, significant, sensible, or appreciable [32]. The reason is that the minor damages that do not effectively harm the interests of the onshore state can be omitted or claim an obligatory indemnity for it since the not-to-harm principle is based on "good-neighboring" and "not to abuse the exploitation of rights." It is logical that there are some damages that cannot omitted when not reaching a level that can threaten the interests of the neighboring state.

The obligation to avoid harming other states is complementary to the Principle of Equitable and Reasonable Utilization usage. Therefore, riparian states cannot justify using it in a way that may profoundly affect its partners under the pretext that it is an Equitable and Reasonable Utilization usage, unless there is an agreement organizing this behavior.

It cannot be denied that Equitable and Reasonable Utilization achievements of the interests would sometimes lead to one or more onshore states bearing some acceptable harm – meaning the harm that cannot be considered appreciable – in the context of what can be defined as the ordinary neighboring risks [33].

When drafting the Convention on the Law of the Non-Navigational Uses of International Watercourses, the International Law Commission used the term "major harm", since there must be an ability to prove the harm objectively. Plus, there must be a real derogation of the right to use, i.e. any harmful consequences on the health, assets, agriculture or the environment in the affected states. Therefore, the "major harm" is the harm which is not slight or viable for the discovery, but it is not necessarily "serious" [17].

Generally, the international outcome on the process of the exploitation of freshwater for non-navigational uses can be summarized as follows [34]:

1. No state should be allowed to execute any work or adopt any behavior that may affect the known rights and interests of other states without prior consultation and agreement with the said states.
2. No state should make any arrangements that may harm other riverine states, such as causing floods or decrease the water share in those states.
3. Each state should refrain from taking any action which may pollute the river or increase the level of contamination in a way that may affect other states. Each state must cooperate with others to prevent pollution or reduce it to the lowest levels possible.
4. Each abuse of the right to use freshwater would be condemned.
5. Any state that behaves in a way similar to the previous point should bear the responsibility in front of the international community.

3 Theories of Riparian States' Rights

Numerous theories tried to pave the way for the rights of each of the riverine countries. They varied from those that tend to give a total priority to the interests of upstream states at the expense of middle and downstream states, and those that tend to give priority to the interests of downstream states not the upstream states, and those that tried to reach compromises and ensure the interests of all the states. Therefore, international jurisprudence has formulated a number of theories in this regard, included in the following sections (for more details about these theories, see [35]).

3.1 The Theory of Absolute Territorial Sovereignty

Supporters of this theory indicate that each riverine state has the full right to exercise on the part of the international river which runs on its grounds all the rights derived from its absolute sovereignty over its territory unconditionally. Regardless of the results and repercussions of the harm caused to other states that the river – or the waterway – passes through any of its regions. The theory gives the upstream state complete freedom to handle the part of the river that runs through its territories regardless of the rights of the other riverine states.

According to this theory, the State has the absolute right to accomplish any projects on the part of the river that runs through its territories whatever those projects are, and whatever their impact or consequences on the neighboring states. This exaggerating theory claims that the state has the right to carry through any changes it sees appropriate to the river, whether these changes constitute a holistic or partial change to the natural course of the river, depriving other states from participating in the basin of the international river and from legal objections. It has the complete right – limitless – in the waters of the river which runs through its territories or emerges from it even if it led to prevent the flow of water to states that are next in order to receive the water or reduce this amount, increase the pollution or cause other damages. This theory tends to maintain the interests of the upstream states.

This theory is also named the “Harmon theory” as the US general prosecutor “Gedson Harmon” drafted it in December, 1895 following a dispute between the USA and Mexico around the usage of Rio Grande water. This dispute was later resolved according to the agreement governing the distribution of water in relation to the agricultural affairs which was signed by the two states (1906) [36].

The Rio Grande River emerges from inside, the USA, in Colorado State, then crosses Texas forming the borders between the American state Texas and Mexico before it pours into the Mexico gulf. The dispute arose when the farmers and cattle breeders in Colorado and New Mexico changed the course or a part of the river, consequently, reducing the amount of water running to the Mexican territories [37].

In the light of this situation, the Mexican ambassador to the USA presented a memorandum of protest to the US Secretary of State where he wrote: “The river course change violates the rights of the Mexican people whose lives depend. Those rights are not debatable because the people started using the water of the river since centuries before the existence of Colorado’s population, and that the conversion work carried out by US farmers have harmed the interests and rights of the State of Mexico” [6].

The US Secretary of State asked the general prosecutor “Harmon” to prepare a legal answer to this objection presented by Mexico. The answer was based, not on the principles of the special laws governing the use of the international rivers as defined by customs and included in the agreements entered by riverine states, but on the notion of sovereignty as an absolute issue. He concluded that the USA is not obliged to pay any indemnities based on its absolute sovereignty on its region which allows it to execute any actions necessary to maintain its interests without the intervention of others. The answer was based on the ruling of the American Federal Court in February, 1812 in the case named: "The Schooner Exchange, V. Mcfadden" which stated that the behaviors adopted by the state on its own territories are an absolute and exclusive right. The only limits are the limits the state should place by itself and that those limits have no other legal or legitimate reference [38].

Harmon compared between this incident and the ruling of the American supreme court in "The Schooner exchange V. Mcfadden" stating that the essential principle in the international law is the sovereignty of the state on its territories and against other states [2].

It seems that Harmon wanted to ease his tone when presenting his opinion, so he added some political considerations and some international complementary rules to solve the problem. Thus he said:

> The Case Presented is a novel one. Whether the circumstances make it possible or proper to take any action from considerations of comity is a question which does not pertain to this department, but The question should be decided as one of policy only...

He concluded that the principles of the international law and rules preceding it do not impose any obligations or implications on the part of the USA [39].

> The rules, principles, and precedents of international law impose no liability or obligation up on the United States.

On the 21st of May, 1906 Rio Grande Convention was signed between the two states. The Convention considered the recommendations of the delegations of both states in the international borders commissions although the convention did not recognize that Mexico has any acquired right or legal clue in the water of Rio Grande River [26].

It is true that the US Secretary of State – based on Harmon's opinion – advised the Mexican government in 1895 that the USA is not obliged to stop the work of diverting the waterway in Colorado and New Mexico, it is also true that some of the upstream states disputes with other onshore states around the common river were based on Harmon's theory – as what Chile did during its dispute with Bolivia around Rio Mory River in 1921 and as India did during its dispute with Pakistan around the Hindu River, similar to the Ethiopian claims regarding the Blue Nile – the theory was not completely accepted and it has no considerable legal consequences since adopting it would threaten the stability of the international relations [40].

This viewpoint expressing the opinion of the USA at that time faced strong opposition not only on the part of Mexico, but also by the majority of the international jurisprudence, including many American scholars, for the following reasons (see [41]):

1. From the political context, the theory leads to instable relations with the neighboring states because the national interest to a state may oppose the national interests of those states, so it is better to integrate those opposite interests not

monopolizing the right to use the river water in the upper part at the expense of the national interest of the state in which the lower part of the river runs.
2. Technically, it is difficult or rather impossible to apply this theory in the case of using the international river to generate electricity since the river forms the borders between two or more states. In this case, it is impossible to evaluate the share of each state of the water needed for this process.
3. This theory goes against the principle of equality among the states located in one river basin; it also violates the principles of justice, as a result of the possibility of the river current reaches the banks more than the other. The state in which the weaker current runs finds itself in a weaker situation more than the other onshore state. In addition, the state located in the lower part will have a weaker situation more than state in which the upper part of the river runs.
4. This theory ignores the reality of mutual dependence among the states located in one river basin. Therefore, limits should be imposed on the regional sovereignty to each state to reach a level of balance between the rights and obligations of the neighboring states. The absolute regional sovereignty does not completely cope with the importance of cooperation between the states.

The USA abandoned this theory later since it holds a weak position as a downstream state, such as when confronting Canada regarding the Colombia River (treaty relating to Cooperative Development of the Water Resources of the Columbia River Basin between the United States of America and Canada of January 17, 1961. S. Exec. Doc. C, 341 UNTS 4; [42]). It even abandoned its stand against Mexico regarding the Rio Grande River. The later dispute was resolved according to the convention and the two states signed on the 21st of May, 1906.

In addition, the American policy adopted contradicts Harmon's notion. In April, 1895 – many months before Harmon adopted his theory – the USA asked Britain – the latter has sovereignty over Canada at that time – to take necessary measures to maintain the rights of the USA and refrain potential harms that may erupt as a result of establishing a dam being executed by a Canadian company on Colombia River in the point which the river crosses the border between the USA and Canada which may drown the lands which Ohio residents have cultivated. When the building was completed, the cultivated lands were flooded. Hence, the US government asked the British government to remove and immediately demolish the dam as well as compensate the American farmers accurately [38].

On the level of the international jurisdiction, there is only a single ruling which supports the theory of absolute sovereignty over the streams that run inside the territories of the onshore states without paying any attention to the notion of not causing any harm. It happened in Austria (1913) when the Austria Supreme Administrative Court ruled in regard to a dispute between Hungary and Austria. Austria had executed some projects on mutual water ways with urging Hungary to resort to the Austrian courts and present allegations regarding the extent of harm which it faced as a result of those projects. But the court refused to consider the element of harm which took place or will take place in the future relying on a strong pretext which is that Austria executed those projects in its own region which is subject to its complete sovereignty and the harm resulting from practicing national sovereignty of a state in its own territories cannot be considered [43].

It is clear that only states located in the upper section or the international river adhere to this theory, meaning the states on whose territories the river emerges or is close to it, because they have the highest interest in the water of the river without being affected by the core of this theory.

It seems clear that this theory relies on the traditional jurisprudence related to the international law, which was adapted to take into consideration the nature of the right of the state in sovereignty its territories, an idea that is no longer acceptable at all in the jurisprudence of contemporary international law. The USA itself amended the theory and many states abandoned it because it violates the principle of just and fair rights to some states and threatening the concept of good neighboring and the international safety and security [44].

3.2 The Theory of Absolute Integrity of the River

This theory illustrates an opposing trend against the theory of absolute territorial sovereignty, named also "The absolute regional integrity theory," and sometimes called "Riparian Rights." It states that to downstream states – Egypt and the Nile – has the right to ask other states – the upstream states – to provide the same amount of water, with the same quality and specifications the river has along its natural course. Therefore, each downstream state can object against and exploitation of the river course if this would lead to any changes to it or to the amount and quality of water.

This means that every state has the right to a certain amount of water runs according to certain momentum in the course of the river, and also has the right to object to change to this status quo, even if the neighboring states have the potentialities which enables them to take advantage of the water in the agricultural and industrial expansion, and even if the geographical location of the downstream state, this does not allow it to execute any expansion or limits its good exploitation of river water.

It is clear that this theory is absolutely biased to the downstream countries, those states have the right to monopolize the water running in its territories, consuming the amounts they desire and use it the way they wish, even if tarnished, and wasting the rest of it in the sea or the ocean uselessly. All other states have an obligation to allow the water to flow naturally and in an integrated way without altering its quality, specification, or speed [45]. And upstream states become a guardian for the upstream states whose main profession is maintaining the water that crosses their territories [24].

Some riparian states adopted the theory of absolute integrity of the river when handling their disputes with others. Some examples include the Indian–Pakistani dispute around Hindu River, Bolivian–Chilean dispute around Mory River, the

Lake Lanoux case on November 16, 1957 between France and Spain. In the last mentioned dispute the court overruled this theory because it provides Spain (a downstream state in this case) the right to object the projects executed by France without bearing any obligation towards any of the other states [46].

If Harmon's Theory was refused because it supports the upstream states, this theory was refused because it supports the downstream states. Both theories ignore the circumstances and the reality, plus ignoring that sovereignty includes rights as well as obligations and duties [45].

Although this theory is useful to the Egyptian interests regarding the River Nile, it is difficult to defend it from the legal and political viewpoints because it leads – similar to Harmon's theory – to illogical consequences, and its application leads to tense political relations within the Nile Basin states.

3.3 The Theory of Common Interest

The Theory of Common Interest is the most developed theory. It is based on ignoring the political riparian borders and considering the whole river as a "basin" which constitutes one geographic, political, economic, and social unit, and that whole length of the river is a hydrological basin. This theory – which is the base upon which Equitable and Reasonable Utilization usage theory is based – is considered the most important theory representing the moderate attitude in comparison to the two other theories. It depends also on the state sovereignty – similar to the other two – but it does not have extreme approaches the other two have. It sees that each state in whose regions an international river runs has the absolute freedom to exploit it the way it sees right provided that it considers and respects the interests of other riparian states. It is obliged not to harm the interests of the other states that share the same river.

The theory is based on the principle of "good neighboring" allowing relations depending on mutual interests regarding the use of the river's water [47] since a sole state cannot enjoy all the interests and advantages the river provides. The states located in the river basin share the same interests. Hence, those interests should be reassigned to enable each state to benefit from them. Each riverine state has a right in an Equitable and Reasonable Utilization share of the river water, its advantages and benefits provided that this will not profoundly harm the interests of the neighboring states. Consequently, it has the right to use the international river, or the section which runs on its territories in an appropriate way, without exceeding this right in a way that would deprive other riparian states from their Equitable and Reasonable Utilization shares.

According to this modern trend in jurisprudence, the international rivers are no longer an ownership of the state that hosts them, or a part of them. They became a mutual natural source shared by all onshore states which are in need for their water. Each state contributes to the maintenance and regulation of this resource [45].

The theory of mutual interests aims at reconciling the interests of the riverine states via adopting the principles of "Equitable and Reasonable Utilization" and "the obligation not to cause significant harm" to other states.

Actually the USA was not the only state that amended the absolute sovereignty theory (Harmon's principle). Many states did the same. For example, India, which officially declared that it adopts Harmon's principle, then refused it in its dispute with Pakistan around the Ganges River. Both states agreed in 1960 to refrain from relying on the principle of sovereignty and adopt the principle of fair and just usage and the obligation not to cause significant harm to others [48].

This theory enjoys a broad range of jurisprudential support.

Consequently, there were practical applications in cases such as the convention on Chad Lake (1964), the convention on Niger Lake (1975), the protocol signed on the 28th of August, 1995 among the SADAC states (Southern Africa Development Commission) under the title "Community Protocol and Shared Water Recourses" concerning the territorial jurisdiction regarding the mutual water resources. It also was adopted by the Permanent Court of International Justice in its judgment dated September 10th, 1929 on the case of territorial jurisdiction of the Oder River (The issue was related to the Oder River navigational uses, and the question on the Permanent Court of International Justice revolves around whether the competence of the Committee on the Oder River includes the tributaries of the river located in Poland or not. The Court has recognized the right of riparian states – including the upstream states to have an access to the sea, and that this dependence plays an important role in establishing the principle of freedom of river navigation in international rivers. For more details on this provision, see [49]).

In addition, the International Arbitrary Commission adopted the same principle regarding the dispute between France and Spain over Lanoux Lake (1957) [50] and the International Justice Court in its rulings regarding the disputes between Hungary and Slovakia on the 25th of September, 1997 [17].

Therefore, most states agreed to refuse the absolute sovereignty notion as a criteria through which waterways and mutual rivers disputes should be settled because this theory – as some claim – opposes the common good of humanity and does not cope with logic or with the facts of international life since the main idea this theory relies on is that there are no international rules that govern the exploitation of the international rivers [51].

4 The No-Harm Rule

The No-Harm Rule is considered one of the most stable theories for centuries regarding the relations among states. Many ancient legal rules mentioned it, such as the Roman law stating: "Use whatever you own and avoid hurting others." ("Sic utero tuo alienam non laedas") [52].

This obligation relies on the principle of good neighboring which urges each neighbor to consider the interests of his neighbors when practicing his powers, and refrain from practicing those powers in a way that may abuse the interests of other neighbors [24].

The core of this principle is that the riverine states must refrain from stopping or diverting the flow of the running river on their territories banning it from reaching other states. They must also refrain from exploiting the water in a way that constitutes a threat to the neighboring states or obstruct the flow of the water hindering an appropriate use of the water by others [53].

This obligation is derived from the fact that sharing the water and its exploitation should be even since each state has rights which are equal to the rights of others. This sharing implies that each state should respect the rights of others and refrain from affecting the water quotas. Meaning that equality regarding the water rights and advantages implies equality regarding responsibilities and obligations [54].

The mentioned obligation is connected – historically – with the notion of sovereignty. So, it entails no legal value since the end of the nineteenth century, especially on the side of the states located in the upstream. They claim they have a sole and exclusive right to use the river unconditionally (for more details, see [26]). This obligation became one of the major principles which governs the exploitation of the rivers and waterways. Each state enjoys an absolute sovereignty over the amount of water running across its territories providing that this does not constitute the interest of the neighboring riparian states [33].

In fact, many states resorted to the obligation "not to harm" as a compromise as far as their relations and water interests are concerned.

Therefore, the Dutch government addressed a letter concerning the Meuse River in 1862 assuring that: "this river is mutual between two states, each of them has the absolute right to exploit it according to the rules of the international law providing that both states refrain from harming the interests of the other state" [32].

On the 12th of January, 1878, the Swiss Federal Court issued a verdict on the case of Argovie C. Zurich depending on the same principle. The verdict reads: "according to the principle of equality, no region or state has the right to take any individual procedures on its own territories that may harm others such as: converting the stream of the river, building dams or any other works that would ban another state from exercising its sovereignty on its water or obstruct it. If any of these harmful actions take place, it would be considered an assault on the region or the state harmed" [55].

In addition, Britain adhered to the same principle in former negotiations related to the convention of 1929 regarding the Nile. It assured that: "the Nile is a sole unit, and Egypt has historical rights in certain amounts of water it is accustomed to obtain and should be maintained and the supply must not be interrupted or that Egypt's right to increase these amounts in the future should not be reduced or negatively affected" [32].

The same stand was reflected in the convention ratified on the 14th of November, 1983 between Hungary and Czechoslovakia. "Both states agreed to acknowledge the rights of the other state to have the half amount of the waters running across the borders placed under each party's disposal in a way that allows each party to benefit from the water without harming the other" [2].

On the level of the international law institutions, the Madrid declaration was issued on the 20th of April, 1911 regarding the use of the international rivers for non-navigational purposes; the declaration was issued by the International Law Complex asserting that: "no state has the right to execute or permit the execution of any works that may hard the interests of another riverine state without a prior approval from the state whose interests are harmed, regardless if those works are executed by individuals or institutions" [56].

In the same context, the Declaration of Montevideo – issued in the 7th conference of the American states on the 24th of December, 1933 regarding the exploitation and use of the international rivers for industrial and agricultural purposes:

> The states have an exclusive right to exploit for industrial or agricultural purposes, under their jurisdiction, the waters of, international, providing, in its exercise it does not affect the equal right due to the neighboring state...

In 1958, the International Law Association issued a decision regarding the use of the international rivers water during a conference held in New York stating that: "each riparian state – excluding what has been stated in an agreement or custom – has the right to obtain a fair share of the river benefits, and each state should respect the rights of other states and refrain from any works that may be considered hostile or which may harm such rights." The fourth Article stated that:

> The duty of a riparian state to respect the legal rights of a co- riparian state includes the duty to prevent others, for whose acts it is responsible under the international law, from violating the legal rights of the other co – riparian states.

The same was stressed in the convention signed by India and Pakistan in 1960 regarding the Hindus River depending on the principle of not harming other [57].

The decision issued by the International Law Complex in 1961 in Salzburg, regarding the non-navigational use of water stated that:

> Every state has the right to make use of the waters flowing across or bordering its territory subject to the limitations imposed by the international law and in particular those Articles which result from following legal dispositions. That right is limited by the right of use by the other states concerned with the same river or watershed [58].

On the 16th of June, 1972, the same was adopted by the Stockholm declaration regarding the environment. The 21st principle reads: "according to the rules of the international law and the principles of UN, each state has the right to exploit – in accordance to its own sovereignty – its own resources in accordance to the policies it practices in the domain of environment providing that this would not lead to harm the environment within another state or in regions that do not enjoy any national sovereignty" [43].

4.1 The Obligation Not to Cause Harm in the Convention on 1997

The UN Convention (1997) stressed the principle not to [59] cause harm in the 7th Article of the convention.

Although the definition of "harm" is clear, there was a severe debate amongst the delegations present around the exact meaning of "harm." This may be derived from the fear of exaggerating the use of the term, whatever its dimensions are.

In other words, the concern that no state will get any international assistance when claiming it was harmed unless the harm has reached a certain level of significance, depending on the stability of the regional circumstances within each group of onshore states that share the same international river. Therefore, the definition of the term went through many stages in order to recognize the set of terms that express the extent of the harm so that we can define it such that "illegitimate harm" which entails that there must be a responsible response. At the start, the term was gross or "substantial," then critical or "sensitive," then "appreciable."

No doubt many terms were ambiguous because they carry multiple meanings according to the different circumstances. So, the International Law Commission wished to apply a single term which can explain the content of the new convention, and "significant" was the choice.

Although the Commission wanted to unify the term, there was a deep dispute and ambiguity regarding the definition of the "harm" and how "substantial" it could be [60].

This meaning stimulated disagreements between two camps around the meaning of the "substantiality" of the harm. One camp adopted the diluted meaning, claiming that when the harm is described as "substantial" as a major condition which qualifies a state to benefit from the 7th Article, it adds to the feeling that the state which caused of the harm cannot be held responsible because the consequence of this action is more important. The action of a state may seem simple, but negative consequences are major and vice versa, it may by major but the action may have minimal harm [61].

There are bearable actions that cannot be described as "substantial" even if they cause harm such as the implementation of drainage projects, taming the river, the maintenance of soil deviation and scavenging, or removing stones, gravel and sand from the river bottom (It should be noted that the first draft of the project in 1991 had suggested the interest of the downstream states by subjecting the principle of equitable and reasonable use of the principle of do no harm. See [62]). This trend is adopted by the downstream states or those located along its middle section, they see that the harm is substantial affecting their shares and interests noticeably.

On the other hand, there exists a radical meaning of the term where substantial harm is a prerequisite for the illegality of the act, and this is the viewpoint of the upstream states [17].

It is the interest of the upstream states to act freely in the international river, even if their actions harm the downstream or middle stream states of the river as long as the harm has not attained the rank "substantial." The substantial harm – in this case – is the harm that affects the interest of one state or a group of states significantly so that they are deprived from benefits and advantages they used to harm, reducing the amount of the water which they used to obtain, diverting the river course, polluting the water, etc. A substantial harm is one that reaches a huge level of significance causing harmful results which can justify the international responsibility against the state which committed the harmful act [24].

It is clear that although the UN Framework Convention (1997) adopted the condition of "substantiality" to recognize the harm that entails international responsibility, some states did not accept this definition in spite of the fact that there is a general acceptance to enlist some actions as causing substantial harm such as (see [63])

1. If a riparian state behaved in a way that impacts the rights and interests of the other states sharing the same river without a prior agreement or without consulting the harmed states.
2. If a state in whose territories an international river runs, takes any arrangements or does any actions that may cause a flood or a reduction of the amounts of water other partner states are obtaining.
3. If a riparian state behaves in a way that pollutes the river or increases its pollution in a way that may harm other states.
4. If a riparian state uses the river in a way that constitutes an abuse to the principle of "the right to use."

Thus, simple offenses do not constitute a breach to the obligations of the riparian states as long as the harm is limited and within acceptable boundaries which the state bears – by virtue of the neighborhood values. No doubt that the relations of neighborliness and partnership in a river should entail – unintentionally – some of the damages that may be caused by the normal use of the river, which cannot be avoided by the state causing the harm or prevent its occurrence. In these cases we have to be referring to these as ordinary and simple harm down to the goodwill and good neighborliness considerations. In addition, sharing the same river – in an Equitable and Reasonable Utilization way – is almost impossible no matter how the states share it, and no matter how accurate the agreements and obligations governing the regulations of the river are, there is always a harm that can be ignored [17].

Finally, it is worth mentioning that the obligation not to cause a substantial harm is not limited only to the obligation of every riparian state, but each state is obliged to refrain from permitting others to use its territories in a way that may cause harm to any state located in the river basin. This means that the state is responsible for any harmful actions and is responsible for the harmful actions of the others as long as it permitted those "others" to use or make advantage of a part of its regions [2]. This theory was applied many times among the American states [64].

In short, the riparian states are not only obliged according to the convention of 1997 not to cause harm to others, but they are also obliged to ban other states from causing this harm. They have a negative obligation via not to cause harm to others, and a positive obligation via banning others from using their territories as a starting point to harm other riparian states.

5 The Principle of Equitable and Reasonable Utilization

This principle circles around the notion that each riparian state is to develop the water course and use it in a fair way to attain the maximum benefits in accordance with known network protection elements and the way it is regulated. Equitable and Reasonable Utilization use means that each state obtains a fair share of the available water resources in a way that leads to enabling each state to obtain the utmost of its needs and interests while avoiding the least damages which may be a result of not obtaining them [65]. It is worth mentioning that Equitable and Reasonable Utilization share does not mean an equal share similar to that other states obtain. One state may obtain a larger amount than the others, in spite of this fact, the principle of Equitable and Reasonable Utilization use is accomplished because what such a state obtains – in the light of different criteria of sharing – is actually its Equitable and Reasonable Utilization share of the river resources [66]. Especially when the Equitable and Reasonable Utilization does not entail that it always comes as a stable share of the water, it may come in the form of participating in benefits which can be achieved using the water not sharing the water itself. Hence, this principle considers the international river – or rather the international water course – as a single economic unit and a mutual water resource regardless of the water boundaries through which the water runs [67]. The principle of Equitable and Reasonable Utilization – based on the theory of common interests – deals with disputing problems in a cooperative way as far as the use of the international rivers water is concerned, it also implies that there must be coordination among the states when there is a desire to execute projects to benefit from the river to avoid the execution of conflicting projects which may result in harming more than one state. It also calls for cooperation to avoid the problems which obstruct obtaining the utmost benefits of the river including pollution, which often requires exerting mutual efforts to overcome it and enable all onshore states to obtain their interests. Almost all contemporary international jurisprudence agree that this notion (not the absolute sovereignty), in addition to the Equitable and Reasonable Utilization of the international rivers waters, is a clear right to all onshore states. Whereas the Equitable and Reasonable Utilization distribution became the most significant pillar upon which the international customs related to the use of river for non-navigational purposes depend, and that it is the part of the law that can resolve international disputes regarding the usage of the river. This was mentioned in Evensen's report to the International Law Commission in 1983 when commenting on the principle of sharing the international water network. He stated that "in the case of mutual natural resource, each state partner in this network has the right to obtain an Equitable and Reasonable Utilization share"[68].

The international practices witnessed a variety of conventions where the signatory parties acknowledged – expressly or implicitly – the basic principles upon which the principle of Equitable and Reasonable Utilization depends. For example, the Yugoslavian–Albanian Agreement (1956), the Soviet–Danish Agreement (1957), and the Brasilia Agreement (1969) (Argentina, Paraguay, Uruguay, Brazil and Bolivia), where the mentioned states agreed to cooperate for the aim of enhancing the development and the financial integration regarding La Plata River. In addition to the convention signed by Burundi, Rwanda and Tanzania (1977) regarding Kagera River, the same principles were adopted regarding the rivers of Senegal, Niger, Gambia, and Chad Lake [69].

The International Law Institute considered the Equitable and Reasonable Utilization distribution and the principle not to harm others as the principles which should govern the relations among the riparian states.

The International Law Association presented some recommendations; the most important of all is called the "Helsinki Rules" (1966).

The same elaboration of the above notion was stressed, and the second chapter's title was: "the Equitable and Reasonable Utilization of International Drain Basin."

The fourth Article states that there is an obligation to respect the Equitable and Reasonable Utilization distribution, while the fifth Article, the second item, numerates some geographical, hydrological, historical, economic, technical, and climate elements which must be considered when sharing.

The same context was complemented by Articles stating that there are no specific uses that a state has a priority upon others (Article 6), no state should limit those uses to be only for its own benefit solely (Article 7) and all uses are considered Equitable and Reasonable Utilization if none of the onshore states prove otherwise (Article 8) [70].

Later, during the conference held in Montreal (1982), the Association issued a decision including a set of rules connected to the pollution of the international drainage basin to complement the contents of the third chapter of the Helsinki Rules (1966).

In fact, this principle has been referred to in many judicial rulings. For example, the conclusion of the Federal Supreme Court of the USA stated that the disputes over the right to the water that runs through the territories of more than one state must be adapted on the basis of "equality of the rights to use." Many states also adopted this in their mutual relations. The dispute raged between the USA and Canada in connection with the interpretation of the 1909 Convention over the Columbia River, the USA declared that the onshore states have the right to share the use of water networks and benefits of the river on Equitable and Reasonable Utilization [71]. The same was confirmed in detail in the Yugoslavian–Albanian Agreement (1956).

The international society witnessed many declarations about the principles concerning the unrestricted sovereignty and the use of river water of international waterways for purposes of agriculture and industry, confirming the generality of the principle of fair use and equitable sharing of the waters of international rivers, for example the Montevideo declaration issued on 24 December 1933 during the 7th American States Conference. It stated: "the states have an exclusive right to exploit the waters of the international rivers running on their own territories for agricultural and industrial purposes but – while practicing this right – they are bound by the obligation not to harm the equal rights enjoyed by the neighboring state on the section that is under that state's sovereignty."

The declaration issued by the Foreign Affairs Ministers of States meeting located in the La Plata Basin (Argentina, Bolivia, Paraguay, Brazil, and Uruguay) on the third of June 1971 stated that: "as far as the consecutives international rivers that do not enjoy the sovereignty of two states are concerned, each state has the right to use the water according to its needs provided that it does not cause any noticeable harm to any other state." [72].

The UN conference in Mar Del Plata, Argentina (1977) assured that the principle of participation in water is based on equal right and sharing of the benefits among the onshore states. It recommended that the states should manage it in a cooperative way. The UN General Assembly declared in its Decree 158/32 on the 19th December, 1977 its acceptance of the suggestions concluded in Mar Del Plata, thus a new legal dimension was added to the principle of sharing the waters and benefit from it fairly [26].

The UN International Law Commission accepted the notion of participation in the water agreement and the importance of benefiting from it fairly. Chopel, the Rapporteur adopted the principle of participation as a base for the rules he suggested in 1982. He suggested that the project should include an Article under the title; "fair participation."

At the level of individual efforts, senior scholars of international law have adhered to the theory of territorial sovereignty and emphasized the fair use and equitable sharing of the waters of international rivers. For example, Humphrey Waldock stated that there is a set of general principles of the law of international watercourses, including that each riparian state owns – principally – an equal right in the benefits of water running on its territories, but while practicing those rights, it should respect the rights of other states, and the onshore state cannot – principally – make any changes to the river network which may harm other states without the approval and satisfaction of the latter. The state cannot object any new projects executed by an onshore state if its rights are not affected by those projects; when two – or more – states dispute, each should agree that the other state has the right to a fair share of the benefits provided by the river network in accordance with its needs while considering all the special circumstances related to this network.

In addition, Luterbacht said: "each downstream riverine state is obliged not to obstruct the water or change the course of the river when flowing towards a neighboring state. It is also obliged to refrain from using the water in a way that endangers the neighboring states or hinders it from using the river course in an appropriate way" [73], whereas Charles Ruso said: "the contemporary international law considers the onshore states of the river as a single regional unit or a regional entity submitted to the principle of the mutual use of the river and its tributaries.

The direct consequence of this principle is the ban of each use which is exclusive to a single state in accordance to its regional sovereignty, especially the ban of each individual behavior or action by the downstream state that may deprive the upstream state from the water." Brownly said: "the individual acts by a certain state, causing circumstances that may harm the other riparian state, entails that this state would bear an international responsibility according to the announced principles mentioned in the ruling related to the Lake Lanoux, and the ruling of the International Justice Court regarding the Corfu strait" [74].

Laws relate the necessity to respect the principle of fair use of the international rivers, and the difficulty to design stable criteria in order to draw the extents of this use in the absence of any agreements or customs that govern this issue or the inability to regulate the dimensions of this use, such as specifying the water amounts needed for irrigation without conflicting with other purposes such as power generation or the reduction of pollution [75]. Yet, this did not prevent the legal attempts to design general rules which can be the guidelines to implement the principle of fair use. All these attempts were derived from the principle of good neighboring which seems to be of a very crucial importance in regard to the relations among the states sharing the same river [76]. The most important and the most renowned are the ones formed by the International Law Association in 1966, or what is known as "Helsinki Rules." The fourth Article of the rules stresses the fair use principle stating that "each state has the right to enjoy an adequate quota of the water within its territories to meet its needs." Then the fifth establishes the foundations of fair use according to the geographical, historical, economic, population, political, and climate consideration to avoid causing harm [77].

Helsinki rules paved the way for the establishment of the factors that should be respected when identifying the fair use as examples not in general to avoid imposing stable rules regarding a very critical subject.

The rule stressed also the importance of the historical rights in the international rivers water and the necessity to consider the population growth, since there is a dependence on the water for being a mutual natural resource (see [78]).

The international works and laws agreed that when implementing the principle of fair use, there are few connected and flexible factors that should be considered when deciding the appropriate and fair quotas for each state individually. Among these factors is the way governing the current distribution of water which are known as the "historical rights," in addition to the social and economic rights to each state as well as the number of population depending on the water in each state and the cost of the alternative resources that can be resorted to in order to obtain water away from the river. Moreover, the possibility of the presence of other resources such as rain and how to avoid unjustified loss, besides the possibility to meet the needs of some of the states without causing a significant harm to another state and the level of compensation [79].

Extrapolation of international treaties in this regard indicates that there is no general rule for the trade-off between one purpose and another of the use of international rivers. Every river has a special status. Thus, the comparison should be based on the special status of each river. This was adopted by the UN convention

(1997). Its 9th Article states that in case there is no contradiction or agreement, there is no inherent priority in regard to the different uses of the international water course (see [80]).

While concerning the stand the UN convention took (1997) regarding the fair use, the 5th Article of the convention was deemed to be the cornerstone for the law connected to this issue.

The most important factor this Article underlines is that it added a new dimension to the principle enabling it to include – not only – the Equitable and Reasonable Utilization, but also the Equitable and Reasonable Utilization at the same time. Then the second item of this Article added the principle of participation, making it obligatory on the side of each state to participate fairly and accurately in exploiting, developing, and protecting the watercourse. It is the item that encourages – indirectly – the cooperation among the states located on the river course, which meets the general obligation of cooperation mentioned in the 8th Article of this convention. The 6th Article highlights – in its first item – the circumstances and the elements which should be considered to identify the Equitable and Reasonable Utilization way of using the waters of the international watercourse [81]. The elements mentioned in the 6th Article can be classified into three categories: natural, historical, and socio-economical [82].

5.1 The Foundations of the Equitable and Reasonable Utilization

Equitable and Reasonable Utilization depends on three foundations: the obligation to cooperate with the onshore states, obligation to notify other states and consult with them in case there is a wish to execute new projects to benefit from the river, and the obligation to ban pollution of the river [79].

5.1.1 Cooperation

The accurate and appropriate implementation of the fair use principle necessitates that all the onshore states become obliged to cooperate with one another to achieve the utmost of the river interests and advantages instead of conflicting to chase narrow national interests as the nature of the river is – in itself – a mutual resource for those states, plus this cooperation meets the core of the principles of good neighboring and goodwill which are supposed to govern the relations among those states.

Many international conventions stressed the obligation to cooperate. For instance, the convention ratified in 1959 regarding the complete use of the Nile waters by Egypt and Sudan. It is considered a typical model in this context. As well as the convention between the USA and Canada in 1961 regarding the waters of the

Colombia River basin, the convention of 1963 ratified by the states of the Niger River basin, the convention of 1963 by Germany, Switzerland, France, Luxemburg, and Netherlands regarding the international protection of the Rein River, the convention of 1968 between Turkey and Bulgaria concerning the cooperation over the use of the flowing rivers in the regions ruled by the two states, the convention of 1972 between Bulgaria and Greece for the establishment of a common committee to cooperate in matters related to electrical powers and the use of the international rivers, the cooperation convention of the Amazon River states in 1978 where the 9th Article stated that all parties should agree on enhancing the cooperation in the domains of scientific research and technology to create appropriate circumstances suitable for economic and social development in the region. The abstract of the Rhine protection convention (22 January 1998) stressed the wish of the parties to develop the cooperative ties to maintain the Rhine River and develop it.

Many jurisprudential efforts and international declarations also stressed the importance of water cooperation. The Article 91 of the recommendations of the United Nations Water Conference held in Mar del Plata in 1977 stated that there must be cooperation among countries in the case of shared water resources in recognition of the growing economic, environmental, and physical interdependence across international borders.

In addition, the 51st Article of the recommendations issued by the UN convention on human environment (1972) stated that it is recommended that the governments would consider committees concerned with the basins and rivers, or any appropriate foundation for the purpose of arranging cooperative activities among those states in the field of mutual resources which are shared by more than one state [83]. The third Article of the chapter on the state's economic rights and obligations stated that when exploiting the mutual resources among different states, each should cooperate via prior notifying and consultations with each other in order to achieve the utmost benefits of the river without harming the legitimate interests of each other. In addition, the treaty governing the use of the international waterways and the international lakes (ratified on 18 March 1992) stated that the parties signatory are aware that using and protecting this water is considered an action on a high level of importance and urgency, only cooperation can help attaining it.

The 8th Article of the UN convention (1997) on the use of the international waterways for non-navigational purposes was titled: "the general obligation is that the waterway states must cooperate on the basis of equality regarding sovereignty, regional unity, goodwill and mutual interests to achieve the ideal use and the appropriate protection of the international waterway" [84].

The 8th Article of the 1997 convention stressed the importance of a general obligation to cooperate between the joint watercourse states to implement the obligation stemming from the convention and identify its objectives and commitments. The second item of the Article calls the parties to establish joint committees and mechanisms to facilitate the mutual cooperation among them. This general obligation entails an obligation to exchange data and information, this obligation was highlighted in Article 9 [79].

The 11th Article of Berlin rules regarding the water resources (2004) stated that the basin states should cooperate to regulate the international drainage basin in order to achieve the mutual benefits.

5.1.2 Prior Notification

Prior notification means that the onshore state which plans to execute a project which changes the nature of the water, use or amend an already existent use in a way that may be harmful to another state should notify the harmed state in advance with the accurate scientific data regarding the project, and allow a considerable period of time to study the project and present its own notes (in case present), in order to minimize the level of the expected harms or even permit them after a mutual agreement where the beneficiary state would be obliged to compensate the harmed state [85]. Therefore, no state is entitled to execute or allow the execution of any water projects on the international river without notifying the other onshore states sharing the same river. Practicing this obligation would help avoid many disputes that may erupt among the states located on the banks of international rivers.

Many conventions and international declarations concerned with the international rivers highlighted the obligation to notify and consult other states, else no compliance would entail that such a state would be responsible before the international society [85].

Clif-x Lachapl treaty between Russia and Holland stressed on the 17th of October, 1816 around the Waldet River. Article 17 Article stated that no state is permitted to make any changes to the course of the river or its banks, plus no concessions are allowed without a prior agreement between the two states involved.

Maastricht treaty (signed by Belgium and Luxemburg on 8 February 1843) stated that neither state has the right to obtain a concession which may affect the rights of the other onshore states without a prior permission.

In addition, the two treaties signed by Austria and Germany regarding the Rhine river on 31 August 1857 and regarding the Danube river on 1 January 1858 asserting the importance of consultations and prior notifications before the execution of any water projects on the two rivers. And the treaty signed by Austria and Germany on 24th of June, 1862 regarding the Danube river stressed the importance of not causing any harm to the other states, and the avoidance of executing any water establishments on the river without a prior agreement between the signatory states. Plus the Portuguese/Spanish treaty signed on the 29th of September, 1864 regarding the Douro River and its assertion on the importance of consultations before any signatory state would attempt to permit hydrological projects on the river course. Then, the treaty signed by France and Spain on the 26th of May, 1866 around the importance of consultations before starting any projects on the river. In addition, there was a treaty signed by Spain and Portugal regarding the Douro river on the 4th of February, 1866, a treaty signed by Germany, France, and Switzerland on the 18th of May, 1887 regarding the Rhine river and Constance Lake, stressing the obligation all the states bear to refrain from building any establishments or make any changes which may obstruct the flow of the river and the lake without a prior agreement by the states signatory, the British–Ethiopian treaty signed on the 15th of May 1902 regarding the obligation of Habesha (Ethiopia) – according to the 3rd Article – to refrain from building or permit the building of any engineering establishments on the Blue Nile, Tana Lake or Sobat River to avoid harming the Nile without a prior agreement with Sudan, the treaty between Norway and Sweden on the 26th of October, 1905, whose second Article stated that no changes to the mutual water basins are allowed without a prior agreement between the two states, the treaty between Britain and Congo on the 21st of May, 1906 where Congo agreed – in accordance with the third Article – to refrain from building any establishments on the Semliki and Yazingo rivers that may reduce the amounts of waters flowing into Albert Lake without a prior agreement from Sudan and the British-American treaty signed on the 11th of January, 1909 stating that building dams in any of the two states may cause harm unless they are submitted to the approval of the other party. In 1911, an international conference was held in which the International Law Institution delivered the "Madrid Declaration" to discuss a variety of aspects related to the legal dimensions of the international rivers. Article 2 Article reads: "no state is allowed to build any establishments on the river without the agreement of other states." The Finnish–Russian treaty signed on the 28th of October, 1922 highlighted the necessity to refrain from executing any works that may negatively affect the water resources course and not to carry on similar establishments on the water systems without a prior notification. Similarly, the Spanish–Portuguese treaty signed in Barcelona on the 11th of August, 1927 regarding the development of the hydroelectric regulations of the Douro River, it included the assertion on the principle of prior notification. The treaty signed by Britain (on behalf of Tanganyika) and Belgium (on Behalf of Rwanda and Burundi) in London on the 23rd of July 1934 regarding the Kagera River as one of Victoria Lake tributaries where the 6th Article states: "the state wishing to use the Kagera River for irrigation purposes should notify other states 6 months in advance to allow those states to study them and present any possible objections." Then came the American–Mexican agreement signed on the 14th of November, 1944 which stated that it is not permitted to execute any establishments on the Rio Grande River without a prior agreement [86], whereas the 5th Article of the Salzburg decision in 1961 (in regard to the non-navigational uses of the international waters) stated that it is not permitted to execute any works or use the river that may affect the potentialities of other states without a prior notification to the concerned states [87]. The Article 2/29 of the Helsinki rules states the importance of prior notifications from the state wishing to execute establishments on the river to the other states in the basin which may be affected in a major way. In his project submitted to the International law Commission in 1982, Chopel adopted the obligation mentioned in the Article 3/8 of the project through asserting the obligations of the basin states to present a notification accompanied by technical data and information to the network states that may be affected by this project or program. The UN convention (1997) adopted the same principle and formed its conditions and limits.

Regarding the timing, it should be carried on in an early stage, in the phase of planning or before the start of work. Regarding its content, it should include detailed technical data and information to enable the other states to evaluate the potential harm accurately (Article 12). The state receiving the notification should be allowed enough and appropriate time to evaluate the potential results of the project, the state sending the notification should not start the project during this period unless the other states agree (Article 13) and (Article 17) [44].

Berlin principles (2004) adopted the same principle; they stated that the basin states should immediately notify each other or the international organizations of any program, plan or project that may have a profound impact.

In contrast, the principle governing the participation in the water and the fair exploitation implies that some of the onshore states should not obstruct the development projects planned by other states or permit them in an abusive way. The state that may be affected – and receives a notification from the state executing a project on the river – to provide a refusing reply or ask for amendments in an attempt to negotiate with the other state according to the principle of goodwill regarding any conflicting aspects.

Therefore, the basic issue is that if the state does not reply to the notification before the appropriate deadline, this would be considered an implied consent on the suggested projects, and the concerned state (planning to execute the project) has the right to start the project without any liability for regular damages. A variety of the international conventions and declarations dealt with this obligation to respond, and all stressed its importance, but neither of them assigned a specific period of time to respond to risks. Montevideo declaration (1993) limited it to 3 months and the basic system of Uruguay River limited it to 180 days, while Articles of the project presented to the International Law Commission (Article 4/8) by Chopel stressed that it should not be shorter than 6 months.

5.1.3 Prevention of Pollution

The obligation to prevent pollution means that the states should refrain from polluting the riparian environment and cooperate to reduce impacts.

Due to the increase in pollution rates and the importance to handle it in an accurate way, many international treaties related to the international rivers and many of the legal and work conventions stressed its crucially [88]. Examples about this are numerous such as the treaties signed by Germany and Luxemburg in 1956, Austria and Hungary in 1956, the Nile convention between Egypt and Sudan in 1959, India and Pakistan in 1960, Argentina and Uruguay in 1961, Belgium and Holland in 1963, the Niger river convention in 1963 too, Poland and the USSR in 1964 and the Senegal river treaty in 1964. The 10th Article of Helsinki rules (1966), the second and third Articles of the International Law Institution decision in Athens (1979) titled: "The Pollution of rivers and lakes and international law, the same rule" and the UN convention in 1997 (Article 21) [89].

Shortly, the general cooperation commitment and the obligations to notify, consult, and prevent pollution is considered a sort of limitation placed on the sovereignty of the onshore states located on the banks of the international rivers for the favor of one another.

The above highlights that there are a set of basics that should respect the Equitable and Reasonable Utilization on the international rivers, the most important of which are respecting the historical rights and respecting the current uses since those rights are related to existent societies for thousands of years where the economic and social circumstances are consequently settled for the same long periods of time. These are circumstances that should not be compromised. In addition, the onshore states sharing one international river are obliged to avoid harming others based on the 7th Article of the UN convention of 1997.

In the light of the above, there are currently some ideas being discussed such as the idea to trade water, i.e., that the upstream states get a financial price from the middle and downstream states in exchange of water or in exchange transporting its waters outside the basin area. This suggestion came to light after Dublin conference which concluded its recommendations in 1992 defining water as merchandise [90]. This recommendation was asserted later by the GWFs until 2015 [91].

Such ideas cannot be acceptable in relation to the mutual basins. If such ideas are accepted in regard to the waters of internal rivers, where the state governing the river has the right to sell its waters or a part of it to other states against fees or free of charge, they cannot be accepted since in regard to the international rivers the water quotas dedicated to each onshore state are right that must not be touched.

5.2 The Relationship Between the Principle of Equitable and Reasonable Utilization, and the No-Harm Rule

The International Law Commission made a slight amendment to the first draft especially concerning the relationship between the "just and fair use," the "principle of not to cause harm" – which are covered by the draft – and the peaceful settlements of disputes. The amended Articles were returned to the 6th committee which decided – as a result of the reaction of the states on the amended Articles – to assigned a special team responsible for forming those Articles in a final version to constitute an international treaty governing and developing the international law continuously [92].

The team met for the first time in the period from the 7th until the 25th of October, 1996 in New York. Its members debated a lot about the draft made by the International Law Commission especially in regard to the terms connected to the impact of the new treaties on the existent ones on watercourses, and the possibility that the onshore states would enter into treaties in the future opposing or at least different from the new treaty. In addition to the relation between the principle of fair use and the principle not to harm other states. This relation was the main problem the International Law Commission should solve [93].

Other meetings were held in the period from the 24th of March until the 4th of April, 1997. Finally, a sort of agreement was reached concerning the most debatable issues which are connected to the principle Equitable and Reasonable Utilization and the principle not to harm.

Due to the mutual absolute respect to the principle of "acquired rights" may hinder the social and economic development k which opposes the principle of equality of the states and not to abuse the right to use the waters of the river, the UN convention(1997) excluded the absolute meaning of the term "acquired rights" and decided that each onshore state has an equitable and reasonable right in the water of the watercourse, considering the states needs for development and the degree its people are in need for water, providing that no harm would be done to the other states [94].

There was no consensus, so some of the terms and the whole convention were put for the vote. Finally, the UN assembly ratified the Convention on the Law of the Non-Navigational Uses of International Watercourses on the 21st of May, 1997 and was submitted for signature (This treaty was annexed to the decision of the UN Assembly No. 229/51 dated 1997 depending on a consensus of 103 votes against 3 (against) (China, Turkey, and Burundi) the opposition of 3 states and the abstaining of 27 states 9 Egypt and Ethiopia). China and Turkey were planning projects on rivers, while Turkey considered that the sovereignty of stave over the natural resources and their rights to regulate those resources was not well considered. It desired that the Articles of the project are limited on the surface waters k because applying them on the groundwater would entail the sharing of those resources – according to its opinion. As for Burundi, it is an upstream state and its vote surprised many especially that it did not participate in the negotiations of the formed team. See [95]).

6 The Legal Status of the Nile River

The absence of a treaty that gathers all the 11 states located along the river Nile, the absence of a permanent international organization to administer the river and develop its benefits and the declaration of some upstream states – Ethiopia for example – of their reservation regarding what they call "rights in the Nile," shed light on the issues related to the rights and obligations of each state and the rules, obligations, and priorities which govern the fair use of the river water in the light of contradicted uses; in addition to the methods of coordination or mutual management of this water in comparison to the universally acknowledged ones and whether there is a strategy through which the benefits of using the river can be upgraded to achieve the mutual advantages of all onshore states without harming the rights they enjoy [96]. Especially that the development requirements in the upstream states and their attempts to change their irrigation systems (into permanent irrigation instead of depending on the rain waters only), the power generation projects and the problems related to the rapid population increase in those states entail that there is a change related to the need of those states for water since the circumstances changed to the extent which urged many of them to demand that Egypt should pay fees for the upstream states in exchange for the water which reaches it, although the Nile water is the only and main source of water to Egypt (for more details, see [97]).

The above does not mean that the 11 states did not enter any agreements or treaties governing the details of their cooperation and obligations regarding the Nile.

There are a number of international agreements and treaties among the Nile Basin states. Yet, all these agreements are either bilateral or trilateral. There is only one treaty which was signed by six states (the framework treaty “Entebbe 2010”). There is no single treaty that is signed by all the Nile Basin states. In fact, those treaties – collectively – form a framework of right and obligations borne by those states regarding the organization or the Nile, including:

6.1 Protocol of 1891

The core of this treaty is the obligation of the signatory parties not to build or execute any water projects on the Ethiopian–Sudanese Atbara River basin without prior consultation with Egypt. On the 15th of April, 1891, Britain and Italy signed a protocol in Rome to determine their influence areas regarding the states of the basin located in East Africa stretching until the Red Sea shores. The third Article of the protocol obliges Italy – having sovereignty over Habesha at that time – to refrain from the execution of any projects on Atbara River in Ethiopia in a way that may noticeably affect the flow of the Nile (see [98]).

This protocol is considered the first ratified treaty regarding the Nile and is considered its legal system. It shows the concern of Britain to regulate all the aspects related to the Nile even if the treaty was not originally related to it [99].

6.2 Treaty of 1902

On the 15th of May, 1902, a treaty was signed between Britain and Ethiopia and between Italy and Ethiopia regarding the borders of the Egyptian/British Sudan, on one hand, and Ethiopia and Eritrea, on the other. The exchange of the signed documents took place on 28 October 1902.

The treaty dealt with three aspects: the borders between Ethiopia and Sudan, the borders of Ethiopia, Sudan and Eritrea and – finally – the borders between the Egyptian/English Sudan, on one hand, and Ethiopia and Eritrea, on the other.

In addition, the British and Sudanese governments were granted the concession of executing a railway from Sudan to Uganda. The emperor Menelik II – the king of kings of Habasha – under Article III of the treaty – pledged not to establish or permit the establishments of any works on the Blue Nile, Tana Lake or the Sobat River that may obstruct the flow of the Nile River without an agreement with the British government and the government of the British/Egyptian Sudan [99].

This treaty clearly stresses the necessity of a prior notification before the execution of any projects by Ethiopia on the Blue Nile, Tana Lake, and Sobat River in a way that may influence the flow of the water. It also aimed at drawing the borders between the Ethiopian empire and Sudan since it stated in the second Article that there should be a committee whose members are assigned by the signatory parties to carry on this task (see [100]).

This treaty has caused – and still – numerous debates especially its third Article due to a misinterpretation of the English text into the Amharic language. The English text stated that both texts – the Amharic and the English – have an official value when drafting the treaty. Britain insisted that the English text shows that the agreement of the English and Sudanese governments on the mentioned works in the third Article is crucial. Finally, the British viewpoint gained merit [24].

It is worth mentioning that the first Article of 1902 treaty included the drawing of the borders between Sudan and Habasha. As a result of this treaty the latter obtained significant areas in Sudan including Bani Shanqool where the "Renaissance Dam" is currently being established.

6.3 The Agreement of 1906 Between Britain and Congo

On the 9th May, 1906, the agreement was ratified between Great Britain and the government of the independent Congo, Belgium signed on behalf of the later since it was, at that time, a private colony for the king of Belgium, Leopold II. In this treaty, the government of Congo undertook – according to the third Article – not to execute or permit the execution of any buildings near or on either the Semliki River or the Isango River which may reduce the amounts of water flowing into Albert Lake without an agreement with the government of the British/Egyptian Sudan [99].

In fact, this treaty secured the Nile equatorial upstream for the favor of Britain, as happened with Habasha before, and pawned every action or working on them to a prior approval from the government of Sudan. This secured the acquired rights for both Sudan and Egypt from any risk caused by states in this zone.

6.4 The Agreement of 1906 (Britain, France, and Italy)

The treaty was signed on 13 December 1906 by the three states. Its fourth Article, item (A) reads: "in the event of circumstances disturbing the current situation mentioned in Article 1, France, Great Britain and Italy should exert the utmost efforts to guarantee the safety of Ethiopia and its unity. In all cases, depending on the treaties mentioned in the above Article, those states should consult and negotiate with each other to secure: the interests of Great Britain and Egypt in the Nile Basin, especially regarding the regulation of the river water and its tributaries while considering the local interests and Italian interests mentioned in item" [99].

6.5 The Exchanges of Notes Between Britain and Italy (1925 Agreement)

There was an exchange of notes signed in Rome with Britain in December, 1925 regarding the concession of executing a reservoir on Tana Lake and a railway from Eritrea to the Italian Somalia across Habasha. The notes state the acknowledgement of the Italian government of the former acquired (and historical) water rights of both Egypt and Sudan in the waters of the Blue and White rivers, undertaking not to execute any establishments in the areas of the upstream, on the tributaries or branches that may amend, noticeably, the amounts of water flowing into the river Nile [99].

Admitting the water rights of both Egypt and Sudan, the notes undertook to refrain from the execution of any works on the main waters of the Blue Nile, the White Nile, their tributaries and branches according to the British request, to meet the economic needs for both Sudan and Egypt in an appropriate way, besides, respecting the rights of the neighboring populations in water.

These notes and the exchanged letters are clear enough to guarantee the acquired water rights of both Egypt and Sudan in the waters of the Blue and White Nile, in addition to their tributaries.

6.6 Agreement of 1929

Was entered regarding the waters of the Nile between Egypt and Great Britain on behalf of Sudan, Kenya, Tanganyika (Tanzania) and Uganda in 1929. The parties agreed to ban all kinds of projects on the river Nile, its tributaries or the lakes that feeds them unless an approval from Egypt is present, especially, if those projects will influence the amounts of water obtained by Egypt or the timing of the flowing of those waters into Egypt. In fact, this agreement – exchanged notes between Egypt and Britain – is considered a prime milestone in the history of the Nile [101]. It highlighted the acknowledgments of all the parties of the acquired rights (On 25 January 1925, the Egyptian prime minister Ahmed Zeiwar Pasha, sent a letter to the British High Commissioner in Egypt saying: "the irrigation system in Sudan should not be of any harm to the Egyptian irrigation system, neither be a threat to the potential projects which are necessary for the accomplish the needs of the Egyptian people who work in fields whose numbers increasingly grow rapidly."

In the next day the British reply said:" … I also assure to your Excellency from now on, the British government – in spite of being interested in the welfare of Sudan – does not intend to harm the historical and natural of Egypt in the Nile We acknowledge these rights today as we have acknowledged them in the past". And in his reply to the notes of the Egyptian prime minister Mohamed Mahmoud Pasha on 7 May 1929, the British commissioner said: "... Finally, I would like to remind your Excellency that the government of his highness the king has already acknowledged the national and historical rights of Egypt in the Nile, and I assert your Excellency that the government of his highness the king considers securing those rights as one of the major principle of the British principles. and I assure your excellency that this principle and the details of the agreement will be implemented at every time regardless of the circumstances that may take place." See [99]). Equitable sharing was also acknowledged (As stated in the memorandum of Egyptian Prime Minister on May 5th, 1929, "Egypt recognizes that the development of Sudan entails that it obtains a larger amount of the Nile waters which it already obtains, therefore Egypt is ready to agree with the British government on an increase which will not harm the increase of the Egyptian natural and historical rights in the Nile or its agricultural expansion." See [102]). It clearly stated that it is not permissible to have irrigation works or power generation works on the Nile, its branches or the lakes feeding it, either in Sudan or in the states under the British management which may reduce the amounts of water flowing into Egypt, amend its flowing times or lower its level in a way that may harm Egypt without a prior approval of the later. It also stated that Egypt has the right to monitor the Nile course from upstream to downstream, and all necessary facilities should be provided to the Egyptian management to study and observe the water researches on the Nile in Sudan.

The agreement of 1929 included an obligation on the other basin states to refrain from executing any irrigation or power generation projects, without a prior agreement with Egypt. And also to avoid adopting any procedures on the Nile, its tributaries or the lakes feeding it that may reduce the amount of water which flows into Egypt, amend its flowing times or lower its level in a way that may harm Egypt.

In addition to the stress of the condition "prior notification," as an obligatory term on the upstream states when executing any projects on the course of the river or on any of its tributaries, the agreement was concerned with regulating the sharing of the water between Egypt and Sudan.

Egypt has achieved many advantages from this agreement. The most important of them all is the acknowledgement by Britain of the natural and historical rights of Egypt in the Nile. This guaranteed to Egypt a superior level of control over the projects and works that will be executed on the Nile for irrigation purposes, not in regard to Sudan only, but in regard to all the states in relation to the issue and were subject to the British influence, i.e., Uganda, Kenya, and Tanzania [103].

6.7 The Agreement of 1934

This agreement was signed in London on 23rd November, 1934, by Britain (on behalf of Tanganyika: current Tanzania) and Belgium (on behalf of Rwanda and Burundi). The first Article of the agreement states that both parties agree to restore any amounts of water which were withdrawn from the Kagera River for power generation purposes before its entrance to the borders area between Tanganyika, Rwanda and Burundi. The permission to use the Nile River water to generate power should not affect the quantities flowing from the upstream areas into its main course [104].

Whereas the 6th Article includes obligations on the state that wishes to exploit the Kagera River for irrigation purposes to notify other states within a period of 6 months before the execution of such projects, in order to allow an appropriate period during which any state can present any possible objections and study them. We can notice that this was the first time that any agreement goes beyond other agreements concerned with the modern irrigation issues to deal with the industrial uses. The importance of this agreement is derived from its stress on the prior notification [105].

6.8 The Exchanged Notes Between Egypt and Britain in 1949

The was an exchange of notes between Egypt and Britain (on behalf of Uganda) in the period from 19 January 1949 to 5 January 1953 regarding the participation of Egypt in the execution of a dam and a reservoir on the Owen waterfalls by the exit of Victoria Lake – work was completed in 1954 – to generate electricity from water in Uganda. Both parties agreed to increase the height of Owen dam to raise water levels in Lake Victoria Nyanza, also agreed to compensate the people of Uganda who may be harmed as a result of rising the water levels at the lake, which will increase the Egyptian share of the irrigation and power generation water and provide Uganda and Kenya with more energy. This agreement is an explicit example on the cooperation and coordination among some of the Nile network states [101]. The agreement included that Egypt will contribute financially to the building of the reservoir whose main purpose is to generate electric power for Uganda in exchange of increasing the Egyptian share in the Nile water which is used for irrigation.

Based on this agreement, Egypt, Sudan, Uganda, Kenya, and Tanzania agreed in 1956 to carry on studies of the basin of Keoga and Albert. The agreement was signed in August, 1967 in cooperation with the UN Development Program, the World Meteorological Organization was responsible to execute the project. The project was named “HydroMet.” On a later date, Rwanda and Burundi joined the project.

Two comments can be drawn regarding the 1953 agreement [106]:

1. The exchanged notes regarding this agreement referred to the agreement of 1929 and vowed to respect it. In addition, it stated that the agreement to build Owen reservoir will be implemented relying on the core of the agreement of 1929. Thus, the agreement of 1953 is – partially – an assertion on the agreement of 1929 which is currently debatable. Consequently, it is an assertion on the importance of securing the water flow into Egypt in the known times and with the same quantities.
2. The agreement of 1953, where Britain vowed on behalf of Uganda that the establishment of the power generation station in Owen and its operation will not reduce the quantities of water flowing into Egypt, amend its arrival times or reduce its levels in a way that may cause any harm to the Egyptian interests. An Egyptian expedition was formed by the Ministry of Irrigation in accordance with the Articles of this agreement to monitor the operations of Owen reservoir and the quantities of the water flowing into it.

There are a number of comments regarding the abovementioned agreements; the first, Britain was the common factor in all the agreements, sometimes representing all the parties of the agreements. Second, there are a variety of principles on which these agreements depended and frequently asserted, the most importance of which are the Egyptian natural and historical rights in the waters of the Nile and the obligation not to harm them directly or indirectly. The third, those agreements included many principles that are an essential part of the current international rivers law such as the cooperation of the basin states, the fair and just use, the obligation not to harm other states, the compensation against the damages resulting from using the river and the prior consultation regarding the potential projects [24].

6.9 Agreement on Full Utilization of the Waters of the Nile Between Egypt and Sudan in 1959

It is the first agreement between two independent states located in the Nile Basin regarding the establishment of the High Dam and the distribution of the resulting benefits between Egypt and Sudan. The agreement is an example on the cooperation among the onshore states for the purpose of using the waters of the international river. It aims at achieving common interests for both states without harming the historical rights of the signatory parties or other states located in the basin. The agreement was signed in Cairo on the 8th November, 1959, and was implemented starting on the 12th of November, 1959. It asserted the obligation to respect the acquired rights of each party and identified those rights precisely to avoid any dispute. In its first Article it recognized the acquired rights of Egypt which equal 48 billion cubic meters per year and four billion for Sudan. In the domain of the river regulation and the distribution of the interests of those projects, both parties agreed – in the second Article – to build the High Dam and share its interests, they also agreed that Egypt will financially compensate the Sudanese citizens who were harmed by this establishment with 15 million Egyptian pounds [107].

In addition, both parties agreed in the third Article to cooperate for the establishment of projects that could minimize the lost waters in the swamps of Jabal sea, Zaraf sea, Ghazal sea, and Sobat River to increase the quantity of the river water, providing that the net interests of those projects will be under the disposal of both states evenly and both will also contribute equally in the cost of the projects. The two parties agreed also to consult each other regarding any future projects whose aim is to enhance the agricultural expansion of both states [108]. Moreover, the fourth Article stated the importance of forming a permanent technical committee to be responsible for the necessary researches and studies needed for the regulation of the river, the increase of its water and monitoring the water meteorology in the upstream areas. This committee is specialized in drawing the main outlines of the projects which aim at increasing the flow of the river and supervising the execution of the projects which the two states plan in this domain (The Jonglei Canal Project is one of the most important projects aiming at reserving the Nile waters from being lost in the marshy areas, however, the outbreak of civil war in southern Sudan has prevented the completion of the project. See about the importance of Jonglei Canal and the obstacles that have prevented the continuation of work by Wahab [109]).

In fact, the agreement is the first Egyptian cooperation with an independent state regarding the Nile Basin after the liberation of this area. The cooperation relied on the refusal of Sudan to the agreement of 1929, and the Egyptian acceptance to the water distribution scheme with Sudan in accordance with the agreement of 1959 (1:3) instead of the scheme stated in the agreement of 1929 (1:12), as a practical implementation of the principle of fair and just use and in the light of all the acquired rights, on one hand, and the distribution of Nasser Lake share, on the other hand [110]. It is a model the other states should follow instead of conflicts around what is left from the water of the Nile after the big lost quantities in the marshy areas.

Some estimate that these amounts reach 90% of the river waters which are lost uselessly. It is worth mentioning that the agreement of 1959 included a legalization of the most important rules of the current international rivers laws which was mentioned in the UN convention in 1997. The agreement depended on the principle of fair and just use and respected one of the most important standards, which is the principle of acquired rights and the former uses which was illustrated in its respect to the historical quota for both of Egypt and Sudan.

It also adopted the principle of “not to harm other states” while conducting the common relations with others regarding the river. In addition, it adopted the principle of cooperation among the onshore states and considered the regulation of compensation procedures when a state is harmed as a result of the establishment of the High Dam. The agreement respected the rights of the others in the waters of the river, and adopted the principle of prior notification in regard to any private project.

Those principles are considered the milestone of the current international rivers law [111].

The agreement of 1959 recognized the rights of the other states in the basin and dealt with the methods necessary to handle them. The second Item of the 5th Article of the agreement reads: “in case a state located on the Nile is demanding a quota of its water, Egypt and Sudan shall agree to study the demands of such state together and agree on a unified opinion about them, if there was a possibility to accept the assignment of any amount of water for a state, this amount – calculated at Aswan – will be deducted equality from the shares of both states” (see [112]).

It is worth mentioning that the Nile Basin states – except Ethiopia – did not have any reservations on the Articles of the agreement of 1959 when it was discussed and ratified, which implies that there is an acceptance to all of them.

As for Ethiopia, it declared a general reservation stating that the mentioned agreement should not harm its rights.

The answer to this position is that the mentioned treaty regulates the historical quotas for both Egypt and Sudan and the mutual obligations regarding the use of those quotas. The main value of this agreement is that it is considered a model of cooperation among the basin states regarding the use of the historical rights without affecting the interests of others or harming their rights. The agreement does not jeopardize the historical water quotas of the upstream states, hence it does not jeopardize the interests and rights of those states, but it regulates the Egyptian and Sudanese use of their quotas which they have been benefiting from historically.

Yet, later, the agreement faced severe criticism by the upstream states because they were not a part of it and were not consulted. In addition, the reference to the natural and historical rights for Egypt and Sudan in the Nile water means maintaining the status quo unchanged.

The agreement of full utilization of the Nile water – implied by the title of the agreement: “Full utilization of the Nile Waters” – means – according to the understanding of these sates – depriving other Nile Basin states from any hope to use it, in addition to the objection of many upstream states claiming that Egypt and Sudan acted solely regarding the assignment of the water.

Ethiopia was the first on the list. The objections reached the highest level when it claimed on 23 December 1957 – during the Egyptian/Sudanese negotiations regarding this agreement – that it maintains its present and future rights in taking all necessary procedures related to the use of its water resources. The objection came in a memorandum issued by the Ethiopian government to its diplomatic mission in Cairo.

Ethiopia elaborated its obligation to meet the needs of its people and economy since it is considered the authentic owner of all the waters running on its territories while contributing to the needs of the neighboring states afterwards.

In fact, the pretexts behind the objections of the Nile Basin states to the agreement are not founded on solid grounds, and cannot be accepted legally. On one hand, those states are considered “the other,” in accordance with the agreement, so there are no mutual obligations tying them to the parties of the agreement unless to the extent imposed by the international law related to agreements, in general. On the other hand, not inviting them to the negotiations or to participate in the agreement is not a violation to law due to the fact that entering a cooperation agreement in the framework of the Nile Basin – similar to other international rivers – can be bilateral.

There is no obligation that all the onshore states should be parties to the agreement, in spite of its importance to achieve the best possible utilization of the river waters. Yet, there is a misinterpretation – seemingly on purpose – of the agreement since it would not be possible for Egypt and Sudan – even if they wish – to utilize the water of the Nile fully when they are not upstream states and get only a small amount of the water. The logical interpretations of the Articles of the agreement – in regard to the full utilization of the water – is that it refers to the Nile section running on their territories, which compromises a smaller quantity in comparison to the total Nile water [113]. The agreement does not oblige other basin states to carry on any duties towards Egypt and Sudan on contrary to the agreement of 1929 which urged those states to bear specific obligations towards both of them as mentioned above. The agreement of 1959 is an absolute bilateral agreement containing mutual obligations by its parties only, the Articles related to other Nile states are connected to the obligations of Egypt and Sudan to adopt a unifying stand towards any demands by those states regarding the water of the Nile. In addition, the permanent mutual technical committee which was formed according to the Articles of the agreement is responsible to monitor the execution of any project on the Nile outside the territories of Egypt and Sudan [114].

6.10 The Agreement of 1991 Between Egypt and Uganda

On 12 May 1991, Egypt and Uganda signed an agreement in a form of exchanged notes between the deputy prime minister and the minister of foreign affairs in Uganda, on the one hand and the Egyptian minister of foreign affairs after intense negotiations between them regarding the establishment of a power generation station on Lake Victoria. Uganda has approached the International Monetary Fund to finance the station (Uganda declared its desire to establish a new station to generate electric power with the financial assistance of the IMF. It sent letters carrying this wish to the embassies of Egypt, Sudan, Tanzania, and Kenya and general note including all the technical details related to the project. Since Egypt and Sudan expressed reservations regarding the project, IMF suspended the financing procedures until Egypt and Uganda can reach an agreement. The two states entered negotiations and reached an agreement in 1991). The agreement included an obligation on Uganda to allow the natural flowing according to the current rates – at the time of the agreement – and full respect of the second Article related to the storage capacity (3 m for Egypt). The third Article states that amendments can be made for the favor of Uganda in order to be able to generate electricity without harming the downstream states, whereas the fourth Article states that the amounts used to generate power should cope with the natural flow rates [115].

Some of the comments on the agreement can be summarized as follows [106]:

1. The agreement was signed by Uganda – which is an independent state – and showed its respect to the Articles included in the agreement of 1953 signed by Britain on its behalf. This illustrates an implicit acceptance by independent Uganda of the agreement of 1929 because the agreement of 1953 – as mentioned above – recognized the agreement of 1929 and asserted its terms and conditions.
2. The agreement of 1991 stated that the regulation policy of the Victoria Lake waters should be discussed and reviewed by both Egypt and Uganda in a matter that would secure the Egyptian water needs [113].

This agreement is considered a good example of the cooperation among the Nile Basin states. Uganda respected the prior notification principle which implies that it should notify the states that are expected to be harmed by the project. It also recognized the principle of the International Treaties Succession via its recognition of the agreement of 1953 related to the Owen reservoir and the storage in Victoria Lake, which is the agreement Britain has signed on its behalf [26].

6.11 The Agreement of 1993 Between Egypt and Ethiopia

On the 1st July, 1993, the Egyptian and the Ethiopian presidents signed “the agreement of Cairo” which drew the general framework of cooperation between the two states for the development of the Nile resources and enhancement of the mutual political and economic interests. The 5th Article of the agreement states that both parties will refrain from any activity that may harm the interests of the other regarding the waters of the Nile. They also agreed, in the 6th Article, to resort to consultation and cooperation regarding the projects of mutual importance with the aim to increase the flow and minimize the lost waters in the light of general and integrated plans. In addition, both parties agreed – in the 7th Article – to establish a consultation mechanism regarding the mutual aspects including the waters of the Nile, whereas in the 8th Article they agreed to reach a cooperation framework among the Nile Basin states which will help enhance the mutual interests to develop the basin of the river [116].

It is worth mentioning that the agreement was ratified by two independent states, therefore it opposes the past Ethiopian claims that the agreements between Egypt and the upstream states were signed when those states were under foreign occupation. In addition, the agreement included a clear and direct agreement by Ethiopia to refrain from causing any harm to the interests of the other party regarding the Nile which means that Ethiopia explicitly recognizes the Egyptian historical rights in those waters.

After the abovementioned presentation of the agreements related to the waters of the Nile, it becomes clear that there are no general international agreements that gather all the Nile Basin states to avoid any disputes that may erupt around the mutual waters with the exception of: the principles of Helsinki international conference (1966), the bilateral agreements entered by some of the basin states, and the principles of the UN framework agreement (1997). The international principles in this regard are general, flexible, and subject to misinterpretation according to the interests of each state and its policies [117].

The water of the Nile is mutual among 11 states. There is no mutual agreement that includes all of them regarding the river basin, therefore, there is a dire need to have a collective agreement relying on the acquired rights of all the parties provided that other parties are not harmed [118].

On the other hand, some see that the absence of a legal framework governing the regional system of the Nile Basin should be ignored since there are three omitted facts [119]:

1. There are a big number of bilateral agreements among the Nile Basin states which have been signed by the United Kingdom and other regions in the basin then those regions became fully independent states. Similar agreements have a legal value equal to the agreements on political borders where the current state respects all the legal agreements and treaties signed by the former states based on the principle of "international succession of the treaties." When the 12th Article of Vienna convention was discussed, it was excluded from the "white journal" of the states which gained their independence recently. The delegations of the Nile Basin states presented declaration affirming this viewpoint.
2. Along centuries a traditional and undisputable custom was adopted regarding the water of the Nile and the uses of its waters.
3. In the light of the desire to reach a general agreement that includes all the Nile Basin states, there are negotiations among all of those states aiming at reaching an agreement that can form a legal framework for the cooperation among them depending on the basic principles related to the uses of the river water which are: "the principle of fair and just use of the river water and the principle not to harm others."

6.12 The Positions of the Nile States Towards the International Rivers Rules and Principles

The recognition of the UN General Assembly to the convention on the Law of the Non-navigational uses of international watercourses in May 1997 raised many debates regarding the extent of its impact on the legal system of the Nile and its relations with the historical international agreement, the methods of sharing the river waters, and the principle of prior notification to avoid harming any state in the basin.

There were severe debates among the riverine states generally and among the Nile Basin states in specific regarding the Articles 3, 5, 6, 7, and 33. The states formed three groups according to its geographical location to the river. The first group included the upstream states such as Turkey, Ethiopia, India, China, and France. The second group included the downstream states such as Egypt, Syria, Iraq, Portugal, Holland, Hungary, Mexico, and Greece. Whereas the third group included states were combining the two situations of being upstream and downstream states at the same time including Finland, Canada, the USA, and South Africa [120].

The geographical location of the Nile Basin states played a major role in the formation of its opinions regarding the issues which stimulated a wide range of disputes during the discussions.

The UN framework convention relation with the former international watercourses – found in big numbers especially in the USA and Europe – was one of the debatable issues among the upstream and downstream states (for more information about the relationship of the Framework Convention previous agreements, see [121]).

Lucius Caflisch stated:

> the issue was not mentioned at all in the draft of the Articles, maybe because the International Law Commission presumed that it is natural to carry on depending on the current agreements without any change, unless the concerned parties of these agreements would amend or cancel them in the light of the new agreement [122].

According to some participants (especially Ethiopia and Portugal), there must be a consideration to some Articles of the new agreement not only as a legalization of the current used customs, but also as an obligatory law. Plus, according to the 64th Article of Vienna agreement (signed in 1969) regarding the law of agreements and treaties, this means all the former agreements regarding the water courses which oppose those rules are void. On the other hand, other states (such as Egypt, France, and Switzerland) declared that the current agreements should not be affected by the new one. In other words, there were two contradicted viewpoints, one sees that the current agreements cannot be influenced at all by any new rules mentioned in the framework agreement due to the fact that the currently used agreements are "private" and should not be affected by the "public," whereas there was another opinion which sees that the current agreements must cope with the new agreement. It is noticeable that the two sides were formed by onshore upstream and downstream states [123].

Regarding the third Article concerned with "the agreements on the watercourses," the dispute was clear in the light of the magnificent importance of this Article for the states of the Nile Basin.

Due to the sensitivity of this Article and being the cause of numerous debates during the final negotiations of the agreement, the Nile Basin states had a big share of those debates, since it touches the heart of the continuous problems among those states following the time of their independence. Their viewpoint was illustrated in their positions regarding the agreements that the occupying forces entered on behalf of them during the occupation period [115]. Therefore, their viewpoint had a big impact on the individual voting process and in the general voting regarding the whole agreement afterwards.

Egypt was one of the main states that adhered to the opinion which adopted that the UN agreement should not affect the former agreements, therefore it suggested in the meeting of the second round (on the 10th October, 1996), to add two items to the third Article of agreement as follows: “1- this agreement does not affect the acquired obligations and rights mentioned in the current agreements and in the acknowledged customs among the states of the watercourses. 2- Yet, the states parties of a current agreement can – if the circumstances permit – consider adapting this agreement with the agreement of all parties.”

This meaning was clear in the statement of the Egyptian delegation in April 1997 and in the meeting of the UN general assembly on 21 May 1997, saying:

> Egypt will only be bound by customary stable rules, such framework agreements cannot – in any way – influence the international bilateral or multilateral treaties related to specific rivers. The delegation of the Republic of Egypt expresses its reservation on the absolute drafting of Article V of the project and it stresses the need to link this principle with the obligations of the riverine states to avoid causing harm to other states.

As for Ethiopia, it adopted a completely different viewpoint believing that the states parties in any former agreements related to the international waterways must – after implementation – review those agreements and amend them to cope with the UN agreement since the last Articles are not legalization to current customs but they are obligations in themselves. In this context, Ethiopia suggested the first Article to be as follows: “1- This agreement is not applicable to the old agreements related to the watercourses except in cases where these agreements constitute a violation to the essential rules and principles stated in this in it. 2- the independent watercourses agreement should not completely be different from the Articles of this agreement. 3- in case there are no bilateral or multilateral agreements among the watercourse states, the Articles of this agreement are valid in regards to the aspects depending on the water course” [124].

That was the reason which urged the Ethiopian delegation to refrain from voting on the agreement when presented to the UN general Assembly on 21 May 1997 although it hailed it when ratified in the “ALL Committee” on 4 April 1997. The Ethiopian representative asserted that his country refused to vote because the agreement does not provide a balance between its Articles and the Articles of the former agreements. It also lacks the necessary balance between the upstream and the downstream states. Yet, Ethiopia changed its stand partially when it expressed that reviewing and adaptation are compulsory [24].

As for Kenya, which did not participate in the initial vote, saw that there is no reason to exclude the former agreements from the framework of this one since it – the agreement of 1997 – aims mainly to state few general principles to facilitate the negotiations related to all the agreements on the international watercourses.

Whereas Uganda declared to the 6th committee that it objects the former agreements, while Sudan – surprisingly – called for a complete review of all the former agreements and adapting them to the UN agreement.

At the end, there was an agreement between the two camps, and the third Article acknowledged the opinion of the second camp – the states wishing to maintain the current agreements (such as Egypt) regarding the international rivers – in an attempt to prioritize the requirements of stability in the riparian states, over the overwhelming desire of eliminating the existing agreements [122]. In addition, granting the states the right to reconsider – when necessary – the adaptation of the former agreements with the essential principles mentioned in the new agreement.

It was logical that the agreement adopts a supporting stand to the second opinion camp through the third Article which asserted that the new agreement does not affect the former agreements in any way (see the text of Article III of this Convention and the comment of Al-Deeb [24]).

Concerning the fair and just use – stated in (Article 5) of the agreement – and the obligation not to cause any considerable harm to other riverine state (Article 7), which are considered the most debatable Articles due to their phrasing and their relation to each other, the general debate concerning them was mainly reflected by the Nile Basin states. Their opinions were similar, but the main dispute was regarding the relation between the two principles and whether one is considered sublime more than the other [125].

Hence, the disagreement between Egypt and Ethiopia became obvious when Egypt desired to prioritize the principle not to harm and measure the just and fair use principle according to it, not vice versa.

Egypt submitted a suggestion regarding the phrasing of the 7th Article as follows: "the states located on the watercourse must take all necessary procedures to benefit from the international watercourse in a way that may not cause any harm to the other states, when such harm is caused, the state causing it – in case a prior agreement is not present – must consult immediately with the harmed state regarding how to eliminate the harm and the methods to do so, including the issuance of special assignments regarding the way to benefit from the watercourse and regarding indemnity."

With the progress of the negotiations, Egypt suggested to put the two principles on equal footings. In April, 1997, the Egyptian delegation issued a statement (presented also to the meeting of the UN General Assembly in May) stating that: "the delegation of A.R.E asserts the principle of fair and just distribution of the international rivers waters and expresses its reservation on the absolute phrasing of the 5th Article of the project". In addition, it asserts the importance of linking this principle with the obligation of the riparian states to avoid causing any harm to other states, plus placing both principles on equal footing. The delegation of A.R.E sees that the phrasing of the 7th Article of the project does not affect the stable customs which was expressed by the International Law Commissions since the start of its work which reads: "Use your rights without harming others." The delegation asserts the obligation of the river basin states not to harm other states which is the milestone of any legal system agreed upon by the parties in regards to the international rivers" [126].

On the other hand, Ethiopia – which was one of the most active states in the initial negotiations – adopted an opposing stand to the Egyptian's. It chose to support the principle of the fair and just use over the principle of not to harm other states, as the milestone upon which the current international rivers law should depend, it also saw that adopting the opposite would lead to give the downstream states the right to "veto" any new uses which other states wish to execute on the pretext that those uses constitute a harm to the others.

As for the standards of the fair and just use of the international rive (Article 6), which are closely related to the 7th and 5th Article, the camp seeking to cancel (Article 7) considered the principle of not harming other states one of the elements which the 6th Article should include, it should not be a separate principle to which a separate Article of the agreement is dedicated. But this opinion was not accepted even by the committee itself. Egypt became one of the group of states which presented a suggestion regarding this Article. The suggestion's core was to add the element of the existence of the other water resources available for the state concerned. The suggestion was not accepted in spite of its grand importance when assigning the quotas of the concerned states which would constitute a threat to its national security, and consequently constitutes a threat to the international peace and security in regard to the relations of the states sharing the same international river. On the other hand, in regard to the elements mentioned in the 6th Article, Ethiopia suggested the addition of an element related to the extent of contribution of each state in relation to the waters of the river, this suggestion was not accepted either [127].

Honestly, the severe disputes regarding the 5th, 6th, and 7th Article (called the "Three-Article Package"), resulting in the committee deciding to submit this "package" for a separate vote. The Nile Basin states' stand (members of the committee) was illustrated in the abstaining of the vote by Egypt, Ethiopia, Sudan and Rwanda and the Tanzanian refusal [26].

In reference to the 10th Article related to relation among the different uses, Egypt declared its objection on the absence of priorities in an absolute way, since irrigation is not always a priority in the dry or semi-dry states. On the other hand, Ethiopia declared its objection regarding relying on the customs when assigning the priorities of the different uses. Rwanda shares the same opinion, while Uganda commented expressing its objection on considering customs as one of the major elements that can assist to assign the priorities when disputes erupt regarding the uses of the watercourse.

In reference to the principle of prior notification, the 13th and 14th Articles presented the concept mentioned in the third chapter in detail, as they dealt with the potential procedures that will be carried on. The 12th Article underlined the obligation of the international river states which plan or permit certain procedures that may cause a significant harm on another state, to notify such state in writing and provide it with all the data and information available regarding those procedures in an appropriate time to enable the concerned state to study and evaluate the consequences mentioned above. The 13th Article referred to the period needed to "respond to the notice period."

Egypt – and most of the participant states – accepted the 13th and 14th Articles and the obligations set in the latter on the state providing the prior notification not to carry on any procedures without the agreement of the state or the states concerned. Yet, Egypt objected the 6 months period. It expressed that "the notice period should be decided upon after an agreement between the concerned parties", whereas there were few amendments suggested by Ethiopia and Tanzania including the replacement of the sentence referring to the 6th month period in the first item of the 13th

Article with the sentence: a considerable period," plus the deletion of the 2nd item of this Article and the 2nd item of the 14th Article.

The importance of these legal texts has risen in the case of the Ethiopian Renaissance Dam by differences in visions between Egypt and Ethiopia on prior notification [128].

As for the 33rd Article which is connected to the peaceful settlements of the international disputes regarding the private rivers, there were many a variety of comments. Egypt objected the phrasing of the 33rd Article severely, and saw that settling the disputes should be dealt with in special agreements. Ethiopia also objected the same Article because the mentioned procedures mentioned are extremely harsh and solid especially in the light that it is a framework agreement. Sudan saw resorting to arbitraries or to courts to settle disputes should be compulsory in order to avoid the possible refusal of the parties to comply with verdict or the decision issued. Rwanda preferred to allow the free choice of how to settle disputes. The 33rd Article was submitted also to a special voting and Egypt, Ethiopia, Sudan, Rwanda, and Tanzania abstained.

The all Articles of the agreement were subject to voting twice. The first time was in the "ALL" committee after the conclusion of the negotiations regarding them. The second took place in the UN General Assembly. In both times, the opinions of the Nile Basin states were different. In the first time, Egypt, Rwanda, Tanzania abstained from a total of 103 states did not participate in the voting process, while Ethiopia and Sudan agreed on the agreement (42 states voted for the agreement). In front of the general Assembly, Sudan and Kenya voted for the agreement, Burundi voted against it and Egypt, Ethiopia, Rwanda, and Tanzania abstained.

Few comments can be expressed regarding the final vote by the Nile Basin states [24]:

1. The absence of Eritrea, Uganda, and the Democratic Congo.
2. The changing Ethiopian position. It voted for the agreement at the start then abstained when voting at the General Assembly.
3. Egypt adopts the same views in both cases by abstaining.
4. The abstaining of many and most important Nile Basin states does not underestimate its importance and does not entail non-compliance with customary principles it stated.
5. Finally, the viewpoint of Burundi (voting for the agreement) was fully surprising when presenting its final vote.

Undoubtedly, the UN agreement as a framework agreement cannot be directly implemented in regard to the relations of the Nile Basin states even if all those states became parties unless there is a special agreement among them reflecting the terms and conditions which are stated in the framework agreement and apply them on the specialty of the Nile. Until then, the Nile Basin states remain obliged to respect the international customs regarding the use of the international rivers waters generally, the regional customs related to the river Nile specifically and the current and applied bilateral and multilateral agreements in this domain [115].

Therefore, Egypt was concerned about the third Article of the agreement which is related to the relation between the new agreement and the current ones which have been referred to – in the agreed phrasing – as not affecting the already implemented agreements among the states sharing the same basin of an international river, this includes the agreements related to the Nile.

The Egyptian statement expressed this meaning clearly when voting on the new agreement, its statement reads: "the delegation of A.R.E asserts that the nature of this agreement as a framework agreement means – in the first place – that it contains a number of principles and general terms related to the non-navigational uses of the international rivers which are based on the agreement and satisfaction of all the states which share the river, the agreement – due to its nature – cannot be directly implemented – in terms of its subject – on the resources of the river basin unless the riverine states enter a special agreement to regulate the relation among them even if all those states are parties of the framework agreement so that the special agreement would consider the special nature of the river including the geographical, historical, hydrological and weather aspects, in addition to the already ratified bilateral and multilateral agreements and the customs related to the use of the Nile waters. According to the general rules of the law, they are the terms that should have the priority – due to its nature – on the terms included in the UN Framework Convention" [115].

In regard to the embodiment of the new agreement of the international customary laws S. McCaffry says: "most of the basic obligations mentioned in the agreement actually embody the customary standards."

Due to the practices of some states three of the general principles included in the agreement cope with the customary standards, they can be summarised as follows [129]:

– The obligation to use the watercourse fairly,
– The obligation not to cause a significant harm,
– The obligation to notify the onshore states which may be affected by the potential works on the watercourse of an international river.

7 Conclusion

Based on the target of the study, which is analyzing the legal dimensions of the international rivers, and then implementing them on the Nile River, it became clear that the economic and technological developments that took place since the second half of the twentieth century led to magnifying the level of interest in the international rivers globally. Consequently, the attention of the onshore states sharing the international rivers was attracted to other riparian uses side by side to the navigational uses. This fact urged the United Nations to focus on this issue through assigning the International Law Commission to prepare a law which can handle the different angels needed to regulate the use of the water. Therefore, the commission put the "Convention on the Law of Non-Navigational Uses of International

Watercourses" on its agenda during its 27th session in 1971 and the session was concluded by the issuance of the UN convention on the law of non-navigational uses of international watercourses (1997).

Although there are many agreements related to the international rivers, which were signed since 1802 (almost 400 bilateral and multilateral agreements), there is no single collective absolute agreement accepted by all of the international society which means that all the rules and principles related to the international law on rivers are relative.

The analysis showed that the principle of fair and just use of the international waterways is the most appropriate legal principle internationally and the best that is suitable for the nature of the international rivers because it considers the differences among the onshore states as far as their water needs, their population, the degree of their economic and social progress are concerned in addition to the absence or presence of river freshwaters alternatives.

In spite of the wide acceptance of this principle by the international jurists and practices, the numerous standards attached to it and being referred to in all the international agreements – such as Helsinki rules (1966), UN agreement (1997) and Berlin rules (2004) – in addition to the special status each international river enjoys solely – and consequently the different standards of the just and fair use standards – led all to the absence of an agreement – in law, practice, and the international judiciary – regarding the priority one or some of the standards have comparing to the others. Therefore, the debate remained in many cases among the onshore states located on the banks of the same international river although they recognize the principle of fair and just use.

The analysis showed also that the obligation on the onshore states to cooperate among each other is one of the most important principles that complement the principle of fair and just use. This general obligation includes an obligation to exchange information, an obligation of prior notification about the projects a state plans to execute on the river – especially the upstream states – and an obligation to practice anti-river water pollution procedures.

The researcher claims that via analyzing the water legal agreements related to the waters of the Nile, whether the ones signed during the occupation or afterwards, the result copes with the views of most of the concerned voices in the Nile Basin (interviewed by the researcher in Egypt, Sudan, Ethiopia, and Kenya) that the regional legal system of the Nile Basin lacks a legal framework. Although there are more than ten agreements to regulate the waters of the Nile, all of them are either bilateral or sometimes trilateral. Hence, there is no collective absolute agreement that includes all the states of the basin. In addition, all the upstream states expressed their refusal to those agreements the same day they gained their independence [130].

On the other hand, the legal framework which was subject to the negotiations in the light of the Nile Basin Initiative (NBI) during the period from 2006 until 2010 failed since six states exited the Nile negotiation mechanism and the individual signature of the Agreement on the Nile River Basin Cooperative Framework of

Entebbe (2010) took place without considering the Egyptian nor the Sudanese viewpoints.

The absence of a legal framework is a weak point in the regional system of the Nile. This situation contributed in the creation of an environment eligible for disputes and debates over the water that can erupt in the basin area from time to time whenever the interests of its states collide (for more details on regional systems theories, see [131]).

From another prospective, the bilateral and multilateral agreements on the Nile form an accurate legal foundation for the rights and obligations of the onshore states. Especially, that those agreements are transparent and is not the starting point of the historical acquired rights of Sudan and Egypt. They are recognized by the International law since they are based on the utilization of the Nile water for a long time – for thousands of years in the case of the Nile – and in an actual and obvious way without any objection from the concerned states, which are the terms stated by the international law – in numerous occasions – when legalizing these rights.

Although some upstream states expressed their objection on the Egyptian-Sudanese keenness to adhere to those agreements on the pretext that they were entered under the umbrella of the occupying powers, and that they are not obliged to recognize them, the analysis proved – undoubtedly – that the claims of the upstream states are groundless as far as the international law is concerned.

The analysis depended on some international agreements, especially the agreement of 1978 regarding the international succession of the treaties, Vienna Convention regarding the laws governing the agreements (1969) and the basics of the African actions adopted since the establishments of the Organization of African Unity in relation to the recognition of the inherited borders – including the disadvantages – in order to maintain the stability of the international relations, security, and peace in the continent. Therefore, the analysis proved the accuracy of the Egyptian/Sudanese position legally.

In an attempt to maximize the utilization of the Nile waters, and strengthen the cooperation among its states, the Nile Basin Initiative – basically an Egyptian proposal – came to live to regulate some aspects of economic cooperation between the states of the basin, create a kind of integration and mutual interest, create a legal and institutional framework that can regulate the water rights of onshore states, remove confusion and conflicting claims, and manage the water of the river to ensure an optimal exploitation and achieve mutual benefits for all of these states, on the other hand.

Although a kind of success was achieved at the level of mutual economic projects, and also despite the agreement on most of the legal and institutional framework aspects, the dispute remained between Egypt and Sudan – on the one hand – and the upstream states – on the other hand – during the negotiation of the legal framework (2006–2010). Egypt and Sudan adhered to the desire that the agreement should include a provision that would ensure the historical and acquired rights, guaranteed by the law which is already present in the existing agreements. They agreed that expressing those rights should be under the term “current uses.” They also adhered to the principle of prior notification about the projects which upstream states plan to execute, a stable and fixed principle according to the actions, jurisprudence and laws.

Finally, both adhered to the notion that any amendment to the framework agreement or any of its annexes should be by consensus or majority which includes Egypt and Sudan which is a logical and reasonable demand to achieve the balance – in such a vital agreement – among a big majority (the upstream states) and a small minority (the two downstream states).

But this dispute obstructs reaching a collective agreement regarding the legal and institutional framework which was signed by five upstream states on 14 May 2010, then joined by Burundi in February 2011.

In fact this dispute, in spite of the strength and clarity of the legal situation for both Egypt and Sudan, is not a legal dispute but basically political. It became obvious in the insistence to start the signature ceremony of the framework agreement (on 14 May 2010) regardless of the participation of Egypt and Sudan, which empties the agreement of its real core since the signature of the framework agreement by the upstream states in the absence of the downstream states means that those states have entered a new agreement outside the legal framework of the NBI. Therefore, it lacks any legal value and only the signatory states are the ones complied before its Articles, whereas Sudan and Egypt are not obliged to follow it. Hence, the same vicious circle of conflicting claims remains.

Based on the sustainable development principle, downstream states have the right to develop their resources and benefit from the advantages they provide in a complete way provided that this takes place through negotiations with the rest of the basin states especially the downstream states.

The mutual benefits of the Nile and exploiting them in a fair way are equivalent to the aspirations of the basin states and the development of their resources in a way that enables them to meet their needs sufficiently. This implies that the rights of the downstream states to enjoy the technology needed to generate power should be considered and respected providing that does not harm the benefits of the downstream peoples. The achievement of their sustainable development is a legitimate right unless that causes harm to the Nile onshore states. The Berlin Declaration (2004) asserted this meaning. It stated in its 7th Article that the states are obliged to take all necessary steps to manage the water in a sustainable way.

In fact, the implementation of the fair and just use principle – including the factors mentioned above – on the case of the Nile River, considering the principle of goodwill in the relations among the basin states while considering the water resources available for the different states, on the one hand, and the economic and social requirements for some of them, on the other hand, is the most ideal way to achieve the mutual interests of all the basin states. Especially that cooperation and mutual work possibilities among those states are vast. For example, the use of the rain water in the basin area.

The quantity of the rain water exceeds 1,660 billion cubic meters per year, only 84 billion of these reach the High Dam, which is equivalent to only 5% of the total rain water. This illustrates the fact that there are huge potentialities and opportunities that can constitute a good base for the cooperation among the Nile states to reserve the big amounts of water that are lost via vaporization in the marshy areas or leak into the underground. There are also huge potentialities and opportunities to establish power generation projects at the waterfalls or through establishing dams on the Nile for this purpose.

In addition, there is a big cooperation potentiality in the agricultural sector using the rains in most of the upstream states [132].

Therefore, consultation and prior notification are the most important principles that each upstream state should adopt if they seek to develop the uses of any development project, this entails that there must be prior consultation with the downstream states before the execution of any dams or establishments that may affect after the quantity and quality of the water [2].

Hence, it can be said that the disputes arising in regard to the water of the Nile and the attempts of the upstream states to change the amounts the downstream states obtain is pointless and a waste precious efforts. Rather, those efforts should have been employed in a way that can secure the benefits of the peoples of the Nile Basin via mutual projects that can help achieve the requirements of the principle of equitable and reasonable use.

References

1. al-Adli M (1999) Water law: the United Nations Convention of 1997 on the law of the use of international watercourses in the non-navigational uses. Arab Renaissance Publishing House, Cairo, p 1 (in Arabic); Black E, Mithen S, Hoskins B, Cornforth R (2010) Water and society: past, present and future. Philos Trans R Soc A Math Phys Eng Sci 368(1931):5107–5110
2. Abdel-Rahman M (1991) The law of the use of international rivers of the non-navigational affairs. Arab Renaissance Publishing House, Cairo, pp 9, 99–110, 118, 332, 399–405 (in Arabic)
3. Gleick PH (1993) An introduction to global fresh water issues. In: Gleick PH (ed) Water in crisis. A guide to the world's fresh water resources. Oxford University Press, New York, pp 13–24; Kulshreshtha SN (1993) World water resources and regional vulnerability: impact of future changes. IIASA, Laxenburg
4. Chou S et al (2001) Water scarcity in river basins as a security problem. Woodrow Wilson Center Environmental Change and Security Project, ECSP Report 3, Aug 9, p 96. http://ecsp.si.edu/ecsplib.nsf
5. Caflisch L (1998) Regulation of the uses of international watercourse. In: Salman SMA, de Chazournes LB (eds) International watercourses: enhancing cooperation and managing conflict. World Bank, Washington, pp 3–4; Darwish A (1994) Water wars: the next major conflict in the Middle East. The Middle East Gulf and North Africa Internet News and Analysis Network, June 1994. http://mideastnews.com/WaterWars.htm. Accessed 4 May 2011
6. Ibrahim A (1997) The law of international rivers and streams in the light of the latest developments and final project of ILC. Arab Renaissance Publishing House, Cairo, pp 29–38, 68–69 (in Arabic)
7. Abdel Mageed Y (1994) The Nile basin: lessons from the Past. In: Biswas AK (ed) International waters of the Middle East. Oxford University Press, Mumbai, pp 172–174
8. Laylin JG (1957) Principles of law governing the use of international rivers. In: 10 Inter-American Bar Ass'n Proceedings, p 146

9. al-Adli M (1999) Water law: the United Nations Convention of 1997 on the law of the use of international watercourses in the non-navigational uses. Arab Renaissance Publishing House, Cairo, pp 20–21
10. Griffin W (1959) The use of waters of international drainage basin under customary international law. Am J Int Law 53:77–79
11. Gouili SS (1998) International river law. Arab Renaissance Publishing House, Cairo, pp 13–14 (in Arabic)
12. The UN (2003) Water for people, water for life. The United Nations World Water Development Report, World Water Assessment Programme, United Nations Publication, pp 252–260
13. al-Mahdi S (2000) The Nile waters: promises and warnings. Al-Ahram Center for Translation and Publishing, Cairo, pp 79–80 (in Arabic)
14. Al-Atawy M-H (1996) Nilopolitics: a hydrological regime 1870-1990. Cairo paper in social science, vol 19(1). American University in Cairo Press, Cairo, pp 3–4
15. Ghonaimy MT (2000) Al-Ghonaimy mediator in the peace law. Knowledge House, Alexandria, p 70 and beyond (in Arabic); Ibrahim A (1997) International rivers and waterways law in the latest developments in the final project to the International Law Commission. Arab Renaissance Publishing House, Cairo, p 70 et seq (in Arabic)
16. McCaffrey S (1995) The International Law Commission adopts draft articles on international watercourses. Am J Int Law 89:395–399
17. Eldin Amer S (2001) The legal system of international rivers. In: Amer S et al (eds) The New International Rivers Act and Arab interests. The Arab League, Arab League Educational, Cultural and Scientific Organization, Arab Research and Studies Institute, Cairo, pp 17–19 et seq, 24–25, 34, 38, 42 (in Arabic)
18. McCaffrey S, Sinjela M (1995) The United Nations Convention on international watercourses. Am J Int Law 92:97–101; International Law Commission (1986) vol 2, pt 2, p 68
19. McCaffrey S (1986) The law of the non-navigational uses of international watercourses. Yearbook of the Internatinal Law Commission, vol 2, pt 2, p 68
20. Goueli SS (1998) International Rivers Act. Arab Renaissance Publishing House, Cairo, p 22 (in Arabic)
21. Alwan MY (1999) The United Nations Convention on international watercourses of 1997. In: Mansour MI (ed) Arab water and the challenges of the twentieth century. Future Studies Center, Assiut University, Asyut, p 113 et seq (in Arabic)
22. Garretson AH, Hayton RD, Olmstead CJ, Baxter R, Teclaff LA (1967) The law of international drainage basins. New York University School of Law, Oceana Publications, Dobbs Ferry; Biswas AK (2008) Management of transboundary waters: an overview. In: Varis O, Tortajada C, Biswas AK (eds) Management of transboundary rivers and lakes. Springer, Berlin, Heidelberg, pp 1–16
23. Ibrahim A (1997) International rivers and waterways law in the light of the latest developments and final project of ILC. Arab Renaissance Publishing House, Cairo, pp 468–469, 550–551 (in Arabic)
24. Al-Deeb IF (2007) Legal natural treaties on the use of the waters of international rivers (international watercourses) in the non-navigation purposes with empirical study of the conventions on the Nile river. PhD thesis, Faculty of Law, Cairo University, pp 41, 58, 144–153, 313 et seq, 361–362, 370–372, 445–450, 452–454 (in Arabic)
25. El-Far AW (1999) Historical and legal rights of Egypt in the waters of the Nile. In: Mansour MI (ed) Arab water and the challenges of the twentieth century. Future Studies Center, Assiut University, Asyut, pp 150–151 (in Arabic)
26. Mahfouz MAM (2009) Egypt's rights in the waters of the Nile in the light of the international law of the rivers. PhD thesis, Faculty of Law, Assiut University, pp 45–48, 59 et seq, 62, 103–104, 176–178, 283 (in Arabic)
27. Rashidi HA (2014) Acquired rights in international law: theoretical study with the application on the rights of Egypt's Nile water. Dar Al Nahda Al Arabia, Cairo, pp 17–18, 40–41 (in Arabic)

28. Lipper J (1967) Equitable utilization. In: Olmeasted GT (ed), The law of international drainage basins. Oceana Publications, New York, pp 26–28; Caponera DA (1985) Patterns of cooperation in International Water Law: principles and institutions. Natl Resour J 25:563–588; Cano G (1989) The development of the law in international water resource and the work of the International Commission. Water Int 14:167–171; Abu-Zeid K (2001) International Water Law from Helsinki rules to the United Nations Convention on the law of the non-navigational uses of international watercourses. Water Resour Impact 3(4):26–31; Wouters P (2000) National and International Water Law: achieving equitable and sustainable use of water resources. Water Int 25:499
29. Lorenz FM (2003) Protection of water facilities under international law. Technical Documents in Hydrology, PC-CP Series, vol 1. UNESCO, International Hydrology Programme (IHP), Paris, pp 6–10
30. Schwebels S (1982) The law of the non-navigational uses of international watercourses. In: Yearbook of the International Law Commission (YBILC), 3rd report, vol II, Part I. United Nations, New York, pp 172–173
31. Wescoat JL (1996) Main currents in early multilateral water treaties: a historical-geographic perspective 1648-1948. Colorado J Int Environ Law Policy 7:39–74; Transboundary Freshwater Dispute Database (TFDD) (2007) Oregon State University. http://www.transboundarywaters.orst.edu/
32. McCaffrey SC (1988) The law of the non-navigational uses of international watercourses. In: Yearbook of the International Law Commission (YBILC), vol II, Part 1. United Nations, New York, pp 80, 139–140, 156
33. al-Adly M (1996) The water resources in the Middle East: conflict or cooperation under the rules of international law. Arab Renaissance Publishing House, Cairo, pp 102, 152–153 (in Arabic)
34. al-Anani I (1998) The legal system of international watercourses is used for international navigation. In: International conference on the water problem in Africa, African Research and Studies Institute at Cairo University, Cairo, 26–27 Oct 1998, pp 109–114 (in Arabic); Vinogradov S, Wouters P, Jones P (2003) Transforming potential conflict into cooperation potential: the role of International Water Law. Technical Documents in Hydrology, PC-CP Series, vol 2. UNESCO (IHP), Paris, pp 12–16
35. Eldin Amer S (2004) The United Nations Convention on the law of the use of international watercourses in the non-navigational uses. Int Politics 158:104 et seq (in Arabic)
36. Littlefield DR (1987) Interstate water conflicts, compromises, and compacts: the Rio Grande (1880-1938). PhD thesis, University of California, Los Angeles
37. Goueli SS (1985) The principle of abuse of the right to public international law. Dar Arab Thought, Cairo, p 656 (in Arabic)
38. McCaffrey S (1996) The Harmon Doctrine. One hundred years later: berried, not praised. Nat Resour J 36(3):552–556, 581
39. Whiteman MM (1963) Digest of international law, vol 1. U.S. Government Printing Office, Washington
40. Godana BA (1985) Africa's shared water resources. F. Pinter, London, pp 35–36; Van Alstyne WW (1960) International law and interstate river disputes. Calif Law Rev 48 (596):606–612. http://scholarship.law.berkeley.edu/californialawreview/vol48/iss4/3
41. Eldin Amer S (2001) Religion, the United Nations Convention on the law of the use of waterways. In: Eldin Amer S et al (eds) The New International Rivers Act and Arab interests. The Arab League, Arab League Educational, Cultural and Scientific Organization, Arab Research and Studies Institute, Cairo, p 104 et seq; see also: McCaffrey S (1996) The Harmon Doctrine. One hundred years later: berried, not praised. Nat Resour J 36(3):580–581
42. Wouters P (1992) Allocation of the non-navigational uses of international watercourses: efforts at codification and the experience of Canada and the United States. Can Year Book Int Law 30(43); Krutilla JV (1967) The Columbia river treaty: the economics of an international river basin development. Resources for the Future, Inc., Baltimore; Northwest Power and

Conservation Council. Columbia river treaty. http://www.nwcouncil.org/history/ColumbiaRiverTreaty.asp; Harrison J (1964) Columbia river treaty. http://www.nwcouncil.org/history/ColumbiaRiverTreaty.asp
43. Moneim AFA (2013) The obligation not to cause substantial harm in the light of the convention on the law of the non-navigational uses of international watercourses of 1997: analytical and empirical study on the Nile. J Contemp. Cairo. The Egyptian Association of Political Economy, Statistics and Legislation (in Arabic)
44. Faraj Allah SP (1998) The United Nations Convention on the use of international watercourses in the non-navigational uses. Political research series, vol 120. Political Studies and Research Center, Cairo University, Cairo, pp 10–11, 14–15, 18–19 (in Arabic)
45. Godana BA (1985) Africa's shared water resources. F. Pinter, London, pp 38–48
46. MacChesney B (1959) Lake Lanoux case (France-Spain). Am J Int Law 53(1):156–171 http://www.jstor.org/stable/2195225
47. Griffin W (1959) The use of waters of international drainage basin under customary international law. Am J Int Law 53(1):60
48. Alam U (2002) Questioning the water wars rational: a case study of the Indus Waters Treaty. Geogr J 168(4):354–364; Biswas A (1992) Indus water treaty: the negotiating process. Water Int 17(44):201–209; Caponera D (1987) International Water Resources Law in the Indus basin. In: Ali M (ed) Water resources policy for Asia, vol 4. Balkema, Boston, pp 509–515
49. Territorial Jurisdiction of the International Commission of the "Oder River", Judgment of 10 December Paper of Court International Justice, Series A, No 23, 1929, at: http://www.worldcourts.com/pcij/eng/decisions/1929.09.10_river_oder.htm
50. Laylin JG, Bianchi RL (1959) The Lake La noux case: the role of adjudication in international river disputes. Am J Int Law 53:30–39
51. Mitchell SM, Zawahri NA (2015) The effectiveness of treaty design in addressing water disputes. J Peace Res 52(2):187–200 jpr.sagepub.com
52. Moermond JO III, Shirley E (1987) A survey of the international law of rivers. Denver J Int Law Policy 16:146
53. Zenati E (1999) The international legal regime of groundwater. In: Mansour MI (ed) Arab water and the challenges of the twentieth century. Future Studies Center, Assiut University, Asyut, p 331 et seq (in Arabic)
54. al-Abadi M (1996) The legal system of international rivers: an empirical theory of the most important rivers of the Middle East. Arab Renaissance Publishing House, Cairo, pp 131–132 (in Arabic)
55. Jafar FZ (2009) The international protection of water resources and water facilities during armed conflict, 1st edn. leaflets Halabi human rights, Beirut, p 129 (in Arabic)
56. Ibrahim A (1995) Rivers and waterways international law, 1st edn. Arab Renaissance Publishing House, Cairo, p 578 (in Arabic)
57. Ibrahim A (1995) Rivers and waterways international law, 1st edn. Arab Renaissance Publishing House, Cairo, p 578. Cairo, the Egyptian General Book Authority, 1976, p 413 et seq; see also: Mehta J (1986) The Indus water treaty. In: Vlachos E, Webb A, Murphy IL (eds) The management of international river basin conflicts. Graduate Program in Science, Technology, and Public Policy, George Washington University, Washington; Ahmad A (2011) Indus waters treaty a dispassionate analysis. Policy Perspect 8(2):73–83
58. Resolution on the Use of International Non-Maritime Waters, Salzburg, 11 September 1961. Article II, at: http://www.transboundarywaters.orst.edu/
59. UN Convention on the law of the non-navigational uses of international watercourses. http://internationalwaterlaw.org/documents/intldocs/watercourse_conv.html
60. Vinogradov S (1992) Observations on the ILC's draft rules on the non-navigational uses of international watercourses: management and domestic remedies. Colorado J Int Environ Law Policy 3:235
61. Mufti A (2001) A study on the convention on the use of international watercourses in the non-navigational uses. In: Eldin Amer S et al (eds) The New International Rivers Act and

Arab interests. The Arab League, Arab League Educational, Cultural and Scientific Organization, Arab Research and Studies Institute, Cairo, p 64 (in Arabic); see also: Beaumont P (2000) The 1997 UN Convention on the law of non-navigational uses of international watercourses: its strengths and weaknesses from a water management perspective and the need for new workable guidelines. Water Resour Dev 4:479–483

62. Mufti A (2001) A study on the convention on the use of international watercourses in the non-navigational uses. In: Eldin Amer S et al (eds) The New International Rivers Act and Arab interests. The Arab League, Arab League Educational, Cultural and Scientific Organization, Arab Research and Studies Institute, Cairo, p 69
63. al-Adly M (1996) The water resources in the Middle East: conflict or cooperation under the rules of international law. Arab Renaissance Publishing House, Cairo, p 151; Mahfouz MAM (2009) Egypt's rights in the waters of the Nile in the light of the international law of the rivers. PhD thesis, Faculty of Law, Assiut University, pp 147–157
64. Van Alstyne WW (1960) International law and interstate river disputes. Calif Law Rev 48:596 http://scholarship.law.berkeley.edu/californialawreview/vol48/iss4/3
65. Benvenisti E (1996) Collective action in the utilization of shared freshwater: the challenges of International Water Resources Law. Am J Int Law 90(3):384–415
66. Hirsh A (1956) Utilization of international rivers in Middle East: a study of Conventional International Law. Am J Int Law 50:81–99
67. Sadoff CW, Grey D (2002) Beyond the river: the benefits of cooperation on international rivers. Water Policy 4:389–403
68. Evensen J (1983) First report on the law of the non-navigational uses of international watercourses. Extract from the Yearbook of the International Law Commission, vol II(1). Document: A/CN.4/367 and Corr.1. http://www.un.org/law/ilc/index.htm
69. Tir J, Stinnett DM (2011) The institutional design of riparian treaties: the role of river issues. J Confl Resolut 55(4):606–631 http://www.jstor.org/page/info/about/policies/terms.jsp
70. Caponera DA (1985) Patterns of cooperation in International Water Law: principles and institutions. Natl Resour J 25:563–588
71. Treaty between the United States and Great Britain relating to boundary waters, and questions arising between the United States and Canada (1909) Washington, Jan 11
72. Ibrahim A (1997) Op. Cit, pp 468–469
73. Oppenheim L, Roxburgh R (1920) International law: a treatise, vol 1. The Law Book Exchange, Ltd., London; Oppenheim L, Lauterpacht H (1953) International law: a treatise. Western Political Q 6(1):214–216. Review by Richard Young. http://www.jstor.org/stable/443474
74. Brwolie I (1979) Principles of public international law, 3rd edn. Oxford University Press, London, pp 271–272
75. Hirsh A (1956) Utilization of international rivers in Middle East: a study of Conventional International Law. Am J Int Law 50:83; Batston RK (1959) The utilization of Nile waters. Int Comp Law Q 8:550–551
76. McCaffrey SC (1986) The law of non-navigational uses of international watercourses. Second report, vol II, part I. Y.B.I.L.C., p 56
77. The Helsinki rules on the uses of the waters of international river, adopted by the International Law Association at the fifty-second conference, held at Helsinki in August 1966 (1967) Report of the Committee on the Uses of the Waters of International Rivers. International Law Association, London
78. Abdel-Rahman M (1991) The law of the use of international rivers of the non-navigational affairs. Arab Renaissance Publishing House, Cairo, pp 215–218; al-Adli M (1999) Water law: the United Nations Convention of 1997 on the law of the use of international watercourses in the non-navigational uses. Arab Renaissance Publishing House, Cairo, pp 117–118; Mahfouz MAM (2009) Egypt's rights in the waters of the Nile in the light of the international law of the rivers. PhD thesis, Faculty of Law, Assiut University, pp 89–91
79. Abdel Aal MS (2002) The legal dimensions of water cooperation among the Nile basin countries. In: A Group of Researchers (eds) Water cooperation between Egypt and the Nile

basin projects. An Egyptian African studies, vol 8. Egyptian African Studies Program, University of Cairo, Cairo, pp 37–42 (in Arabic)
80. Abdel-Rahman M (1991) The law of the use of international rivers of the non-navigational affairs. Arab Renaissance Publishing House, Cairo, pp 422–423; Faraj Allah SP (1998) The United Nations Convention on the use of international watercourses in the non-navigational uses. Political research series, vol 120. Political Studies and Research Center, Cairo University, Cairo, p 13
81. Convention on the law of the non-navigational uses of international watercourses (1997) Adopted by the General Assembly of the United Nations on 21 May 1997. http://internationalwaterlaw.org/documents/intldocs/watercourse_conv.html. Accessed 1 May 1997
82. Majzoub T (2001) New legal regime of international rivers in the light of the Arab interests. In: Eldin Amer S et al (eds) The New International Rivers Act and Arab interests. The Arab League, Arab League Educational, Cultural and Scientific Organization, Arab Research and Studies Institute, Cairo, pp 320–322 (in Arabic)
83. McCaffrey SC (1987) The law of the non-navigational uses of international watercourses. Third report. Y.B.I.L.C., pp 43–44
84. McCaffrey SC (2001) The law of international watercourses: non-navigational uses. Oxford Press, Oxford
85. Kaya I (2003) Equitable utilization: the law of the non-navigational uses of international watercourses. Ashgate, Hampshire, pp 129–137, 140
86. Treaty between the United States of America and Mexico relating to the utilization of the waters of the Colorado and Tijuana rivers, and of the Rio Grande (Rio Bravo) from Fort Quitman, Texas, to the Gulf of Mexico (1944) 3 UNTS 314, 3 Feb
87. Transboundary Freshwater Dispute Database (TFDD) (2007) Oregon State University. http://www.transboundarywaters.orst.edu/; International Freshwater Treaties Database. http://www.transboundarywaters.orst.edu/database/interfreshtreatdata.html; Wescoat JL (1996) Main currents in early multilateral water treaties: a historical-geographic perspective 1648-1948. Colorado J Int Environ Law Policy 7:39–74
88. Schwebels S (1982) The law of the non-navigational uses of international watercourses. Third report, vol II, part I. Y.B.I.L.C., pp 225–229
89. Transboundary Freshwater Dispute Database (TFDD) (2007) Oregon State University. http://www.transboundarywaters.orst.edu/
90. United Nations Environmental Program (1992) Final report of the international conference on water and environment, Dublin
91. World Water Council (2000) A vision for world water at the millennium. Prepared for the World Water Forum, World Water Council, The Hague
92. Eldin Amer S (2001) The United Nations Convention on the law of the use of international watercourses. In: Eldin Amer S et al (eds) The New International Rivers Act and Arab interests. The Arab League, Arab League Educational, Cultural and Scientific Organization, Arab Research and Studies Institute, Cairo, p 11
93. Caflisch L (1998) Regulation of the uses of international watercourse. In: Salman SMA, de Chazournes LB (eds) International watercourses: enhancing cooperation and managing conflict. World Bank Technical Paper No. 414. World Bank, Washington, pp 13–15; Crook J, McCaffrey S (1997) The U.N. starts work on a watercourses convention. Am J Int Law 91:374; McCaffrey S (1995) The International Law Commission adopts draft articles on international watercourses. Am J Int Law 89:395
94. Almusa SS (1998) Harmonizing equitable utilization and significant harm: comments on the 1997 ILC Convention. In: Conference on water dispute prevention and development: South perspectives, Center for the Global South, American University, Washington, Oct 1998, pp 5–13. http://gurukul.Ucc.american.edu/maksoud/water98/present7.html
95. Tanzi A (1997) Codifying the minimum standards of the law of international watercourses: remarks on Part one and a half. Nat Resour J 21:109; Crook J, McCaffrey S (1997) The

United Nations starts work on a watercourse convention. Am J Int Law 91:374; McCaffrey S, Sinjela M (1997) The 1997 United Nations Convention on international water courses. Am J Int Law: 97

96. Ouda AE (1998) Some of the Nile river issues in the light of the law and agreement of the use of international waterways in the non-navigational uses. In: Faraj Allah SP (ed) The United Nations Convention on the use of international watercourses in the non-navigational uses. Political research series, vol 120. Political Studies and Research Center, Cairo University, Cairo, p 23 (in Arabic); Batstone RK (1959) The utilization of the Nile water. Int Comp Law Q 8(3):523–558
97. Tayie MS (2012) Egypt and the Nile water crisis: prospects for conflict and cooperation. Dar Al Shorouk, Cairo, pp 298–321 (in Arabic); Zeid MA (1998) Water: a source of tension in the 21st century. Al-Ahram Center for Translation and Publishing, Cairo, pp 135–137 (in Arabic)
98. Protocol delimiting spheres of influence in East Africa, signed April 15, 1891, Italy, United Kingdom (1891) Article (3)
99. Egyptian Foreign Ministry (1983) Egypt and the Nile river. The Egyptian Foreign Ministry, Cairo, pp 39, 52, 59, 63–64, 69–79 (in Arabic)
100. Treaties retune to the frontiers between the Sudan Ethiopia and Eritrea, signed May 15, 1902, Ethiopia–Italy–U.K. (1902) Article (3)
101. Fahmi A (1967) International River Law for non navigable rivers with special reference to the Nile. Egyptian J Int Law 23:46–47, 207–239
102. Krishna R (1995) The legal system of the Nile. In: Starr J, Stoll D (eds) Scarce policies: water in the Middle East (trans: Khadr A). Ain for the Humanities Studies and Social Research, Cairo, pp 34–35
103. Egyptian Foreign Ministry (1983) Egypt and the Nile river. The Egyptian Foreign Ministry, Cairo, p 82; see also McCaffrey SC (1993) Water, politics, and international law. In: Gleick PH (ed) Water in crisis. A guide to the world's fresh water resources. Oxford University Press, New York, p 94
104. Egyptian Foreign Ministry (1983) Egypt and the Nile river. The Egyptian Foreign Ministry, Cairo, pp 38–45; Sultan H (1966) International rivers in the Arab world. Egyptian J Int Law 22:13–23; Krishna R (1995) The legal system of the Nile. In: Starr J, Stoll D (eds) Scarce policies: water in the Middle East (trans: Khadr A). Ain for the Humanities Studies and Social Research, Cairo, pp 33–38 (in Arabic)
105. Abdo AI (1964) River immortal. Casablanca National Printing and Publishing, Cairo, p 188 (in Arabic)
106. Zeid MA (2004) Egypt and the Southern Nile countries. Al-Ahram Almasey, 20 Mar 2004 (in Arabic)
107. Hassanein FA (1997) The water and the cards of the political game in the Middle East. MM Library, Cairo, p 69 (in Arabic)
108. Tayie MS (2005) Scarce of water resources and international conflict: the case study of the Nile river basin. PhD thesis, Faculty of Economics and Political Science, Cairo University, pp 197–201 (in Arabic)
109. Wahab AA (2000) Water resources of Egypt and the development projects: a case study of Jonglei Project. In: El-Naggar AS (ed) Water and agriculture in Egypt. Center for Political and Strategic Studies, Cairo, pp 134–135 (in Arabic); Bulloch J, Darwish A (1993) Water wars: coming conflict in the Middle East. Victor Gollanncz, London, pp 135–139
110. Ouda AM (1999) Egyptian politics and the Nile water in the twentieth century. Center for Political and Strategic Studies in Al-Ahram, Cairo, pp 35–36 (in Arabic); Elkosy DE (2004) The optimal use of the waters of the Nile basin. Int Polit 158:91 (in Arabic)
111. Eldin Amer S (2007) Introduction to the study of Public International Law. Arab Renaissance Publishing House, Cairo, pp 492–495 (in Arabic); Al-Deeb IF (2007) Legal natural treaties on the use of the waters of international rivers (international watercourses) in the non-navigation purposes with empirical study of the conventions on the Nile river. PhD thesis, Faculty of Law, Cairo University, pp 380–381

112. Zeid MA (2004) The Nile water agreements with Sudan. Al-Ahram Al Msaey, 27 Mar 2004 (in Arabic); The text of the agreement in 1959; Abdo AI (1964) River immortal. Casablanca National Printing and Publishing, Cairo, p 191
113. Badr M (2002) The political dimensions of the projects of water cooperation among the Nile basin countries. In: A Group of Researchers (eds) Water cooperation between Egypt and the Nile basin projects. An Egyptian African studies, vol 8. Egyptian African Studies Program, University of Cairo, Cairo, pp 17–20
114. Kliot N (1994) Resources and conflict in the Middle East. Rutledge, London, pp 84–88
115. Eldin Amer S (2001) Nile river: the international legal system governing the utilization of its waters. In: Amer S et al (eds) The New International Rivers Act and Arab interests. The Arab League, Arab League Educational, Cultural and Scientific Organization, Arab Research and Studies Institute, Cairo, pp 139–140, 143–146
116. Ouda AM (1999) Egyptian politics and the Nile water in the twentieth century. Center for Political and Strategic Studies in Al-Ahram, Cairo, pp 58–59
117. Hillel D (1994) Rivers of Eden: the struggle for water and the quest for peace in the Middle East. Oxford University Press, New York, pp 138–142
118. Allan AJ (ed) (1995) Water in the Middle East: legal Middle East studies. I.B. Tauris, London, New York, p 177
119. Interview with Salah Eldin Amer, a professor of public international law, Cairo University, in Cairo, 15 Jan 2005. See also Garretson A (1967) The Nile basin. In: Garretson A, Haytion R, Olmstead C (eds) The Law of International Drainage Basins. Oceana, Dobbs Ferry, p 256
120. Redelinghuys N, Pelser AJ (2013) Challenges to cooperation on water utilisation in the Southern Africa region. Water Policy 15:554–569
121. Alwan MY (1999) The United Nations Convention on international watercourses of 1997. In: Mansour MI (ed) Arab water and the challenges of the twentieth century. Future Studies Center, Assiut University, Asyut, pp 113–120; Eldin Amer S (2004) The United Nations Convention on the law of the use of international watercourses in the non-navigational uses. Int Politics 158:109
122. Caflisch L (1998) Regulation of the uses of international watercourse. In: Salman SMA, de Chazournes LB (eds), International watercourses: enhancing cooperation and managing conflict. World Bank, Washington, pp 3–16
123. Crook J, McCaffrey S (1997) The U.N. starts work on a watercourse convention. Am J Int Law 91:374–375
124. Flint C (1995) Recent developments of the International Law Commission regarding international watercourses and their implications for the Nile river. Water Int 20:197–202
125. Wouters P (1999) The legal response to international water conflicts: the UN watercourses convention and beyond. German Year Book Int Law 42:293
126. Eldin Amer S (2007) Introduction to the study of Public International Law. Arab Renaissance Publishing House, Cairo, pp 470–471
127. Bulto ST (2009) Between ambivalence and necessity: occlusions on the path towards a basin-wide treaty in the Nile basin. Colorado J Int Environ Law Policy 20:291–320
128. Shteiwi MA (2016) Principles of international law governing the construction of dams on international rivers: an empirical study on the Ethiopian Renaissance Dam. Dar Nile for Publishing and Printing and Distribution, Cairo, pp 109–115
129. McCaffrey SC (1998) The UN Convention on the law of the non-navigational uses of international watercourses: prospects and pitfalls. In: Salman SMA, de Chazournes LB (eds) International watercourses: enhancing cooperation and managing conflict. World Bank Technical Paper No. 414. World Bank, Washington, pp 26–27; McCaffrey SC, Sinjela M (1997) The 1997 United Nations Convention on international watercourses. Am J Int Law: 92–97; McCaffrey S (1985) Special Rapporteur, preliminary report on the law of the non-navigational uses of international watercourses. Document A/CN.4/393. Year Book of International Law Commission, p 87; McCaffrey S (1986) Second report on the law of non-navigational uses of international watercourses. Document A/CN.4/399 and Add.1 and

2. Yearbook Book of International Law Commission, vol II, part 1, p 87; McCaffrey S (1987). Third report on the law of non-navigational uses of international watercourses. Document A/CN.4/406 and Add.1 and 2. Year Book of International Law Commission, p 15; McCaffrey S (1988) Fourth report on the law of non-navigational uses of international watercourses. Document A/CN.4/412 and Add.1 and 2. Year Book of International Law Commission, p 205; McCaffrey S (1989) Fifth report on the law of the non-navigational uses of international watercourses. Document A/CN.4/421 and Add.1 and 2. Year Book of International Law Commission, vol II, part 2, p 91; McCaffrey S (1990) Sixth report on the law of the non-navigational uses of international watercourses. Document A/CN.4/427 and Add.1. Year Book of International Law Commission, p 41; McCaffrey S (1991) Seventh report on the law of the non-navigational uses of international watercourses. Document A/CN.4/436. Year Book of International Law Commission, p 45

130. Dellapenna JW (2002) The Nile as a legal and political structure. In: Castelein S, Otle A (eds) Conflict and co-operation related to international water resources: historical perspectives. Selected papers of the (I.W.H.A) conference on the role of water in history and development, Bergen, 10–12 Aug 2001, International hydrological programme, technical documents in hydrology, vol 62. UNESCO, Paris, pp 35–47
131. Krasner SD (1982) Structural causes and regime consequences: regimes as intervening variables. Int Org 36(2):185–205
132. Wouters P (2000) The relevance and role of water law in the sustainable development of freshwater: from hydrosovereignty to hydrosolidarity. Water Int 25(2):202

Part VII
The Nile River: Conclusions

The Nile River: Conclusions and Recommendations

Abdelazim M. Negm

Abstract Instead of being a source of cooperation for sustainable development, it becomes a source of conflict. It is the Nile River which is the longest river in the world, although its discharge is less than 1.5% of the Amazon River discharge. The Nile River volume of the Handbook of Environmental Chemistry describes in detail several important aspects of the river. These aspects include the Nile journey from origin to end, the water and sediment qualities, the morphology and the stability of its promontory at its end, rainfed agriculture and fish and fisheries in the Nile Basin, climate change variability, vulnerability, mitigation and adaptation measures, legal and international aspects and its hydropolitics. These contents are covered in 23 chapters. On the other hand, the most highlighted conclusions and recommendations of the 23 chapters of the Nile River volume are presented in this chapter.

Keywords Climate change, Ecosystem, Hydropolitics, Legal aspects, Nile Basin, Rainfed agriculture, Sediment assessment, Sustainable management, Water quality assessment

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A.M. Negm (✉)
Water and Water Structures Engineering Department, Faculty of Engineering, Zagazig University, Zagazig 44519, Egypt
e-mail: amnegm85@yahoo.com; amnegm@zu.edu.eg

A.M. Negm (ed.), *The Nile River*,
Hdb Env Chem (2017) 56: 719–730, DOI 10.1007/698_2017_18,

1 Summary

Recently, the international rivers like the Nile River have attracted the attention of the researchers. Although the Nile River is the longest river in the world, the area of its watershed comes at the 6th order, and its annual flow appears at the 24th order. In this volume, the Nile River journey is described from the Nile origin to its end. The lifetime span of the Aswan High Dam Reservoir (AHDR) is estimated using different approaches and the maximum deviation is found to be within 2–16%. The water quality of AHDR is reviewed. The morphology, the ecosystem, the water quality, and sediment quality along the Nile River are discussed and presented. The stability of Rosetta promontory via hydrodynamic modeling is proposed along with the estimated costs. Also the different methods for coastal zone protection zone are reviewed. Moreover, several international issues are discussed in detail. These issues include impacts of mega projects like GERD at the Upper Nile on the downstream countries. Fish and fisheries aspects in the Nile Basin and the challenges facing this important industry are discussed and several management issues are raised for improving the productivity. The climate change impacts and its variability, vulnerability, mitigation, and adaptation measures are emphsized. The extent of the required cooperation among the Nile Basin countries to face the climate changes' impacts is focused. The legal and international aspects that proof the rights of Egypt in the Nile River water share of 55.5 BCM are verified. The main hydropolitics of the Nile River Basin are discussed.

In the next sections, conclusions and recommendations of the different chapters are presented. Also, some others from recently published research works are stated for the purpose of updating.

2 Conclusions

The following conclusions could be stated:

1. The Nile River basin is very rich in its natural resources including water as the main source of life, but lack of cooperative management makes these as if they were not existing. Moreover, the absence of an organizing collaborative and integrated legal framework among all Nile Basin states increases the potential international conflicts among the Nile Basin states.
2. The Life Time Span of Dead Zone (LTSDZ) is equal to 254 years and the Life Time Span of Life Zone (LTSLZ) is equal to 964 years based on numerical simulation using CCHE2D. However, it should be noted that this lifetime span will not be significantly affected in the future because after the construction of the GERD the sediment will be retained in its reservoir. However, the pattern of the accumulated sediment in the AHDR will be modified as a result of the almost clear coming water to AHDR. On the other hand, the satellite remote sensing approach is used to estimate the lifetime of the AHDR. The LTSDS and

LTSLZ are estimated to be 478 years and 830 years. Moreover, the estimations based on the cross section method that was adopted by Aswan High Dam Authority are found to be 487 years and 833 years.

3. Results indicated that the Lake Nubia water quality status ranges from excellent to good, compared to the Egyptian water quality standards for fresh surface waterways. Also, results of the applied trophic status indices show that the Lake Nubia trophic status is eutrophic. The Carlson TSI, based on total phosphorus, indicates that the trophic status of Lake Nubia is hypereutrophic. Also, results indicated that reservoir zones should be assigned to different water use according to its water quality and trophic status due to the impact of the Lake morphology and water quality and trophic.
4. A 3-D model is built for the Lake Nubia using GIS and the collected data over an extensive period. Then, a satellite remote sensing approach is used to estimate the sediment amount in the AHDR. The estimated amount of sediment using RS/GIS deviates by 4% from the cross section methods which is utilized by the associated authorities of the Lake. This means that RS/GIS approach overestimates the accumulated sediment by 4% compared to the cross section method.
5. Rating curves for Nubia Lake are developed, and the accuracy of the developed relationships is assessed by comparing the results with the observed data and the current rating curves for the lake.
6. The study of the multi-temporal morphological changes in water surface areas of the first reach (from Aswan to Esna Barrages) and the second reach (from Esna Barrages to Naga Hammadi Barrages) of the Nile River is presented. The RS/GIS technologies based on using Landsat images indicate that total water surface area of the first reach of the Nile River over the period between the year 1984 and the year 2011 is decreased by about 2.39 km^2 (2.3% of total area). It is observed that the maximal changes are located around the reach islands. While for the second reach, the results show that the total decrease in the area of the second reach of the Nile River over the period (1984–2010) is about 13.14 km^2 (about 13% of the total water area in the year 1984). Moreover, the results illustrate that the maximum decrease of this studied reach water surface area occur through the period (2005–2010) is about 8.33 km^2. It should be mentioned that most changes in this reach occurred in the river banks due to the accumulated sediment annually (sedimentation process).
7. The use of the different change detection methods indicates the superiority of the NDWI method for water change detection compared with other methods. Its overall accuracy is 99.23% for the first reach while it is 99.13% for the second reach.
8. Results of the 2-D modeling of the bed morphology of the Nile River downstream of Naga Hammadi barrages show the importance of bed morphological simulations and demonstrate the requirement of having stochastic runs to supplement the deterministic analysis.
9. The distribution of the natural radioactivity in the sediments of the Nile River from downstream Aswan to El-Minia is reviewed. The results reveal that the

natural radioactive elements such as ^{238}U, ^{232}Th, and ^{40}K have been detected with spatial variation along the study area. However, the variation of the distribution of the detected elements depends on many factors as listed in the relevant chapter.

10. In general, the Nile water is suitable for human consumption after regular treatments in water treatment stations. However, during the low flow periods, some harmful pollutants might be recorded such as heavy metals and fecal coliform bacteria.
11. The water quality along the Nile River from Aswan to Assiut changes from low to high flow and from one place to another according to human activities based on the measured water quality parameters for two successive years 2011 and 2012 at ten sites. The measured physical and chemical parameters include temperature, turbidity, water electrical conductivity (EC), total suspended solids (TSS) and total dissolved solids (TDS), pH value, dissolved oxygen (DO), nutrients, biological oxygen demand (BOD), chemical oxygen demand (COD), total organic carbon (TOC), major anions and cations, hardness, heavy metals, and fecal coliform bacteria. Results indicate that the water pollution increases with distance from the Aswan High Dam to the north due to untreated agricultural drainage water flowing by gravity back to the Nile. Industrial and sewage water are controlling factors in polluting the Nile River water. The water quality of the Nile Water is classified as medium. Moreover, eutrophication of the water caused by organic and inorganic pollutants cause the overgrowth of some algae that secrete toxins which affect water quality and especially drinking water from the Nile. Some specific algae cause odor, smell or taste problems.
12. The results of the hydrodynamics simulation of the Nile River (Damietta Branch reach) from 26.5 to 116.5 km downstream EL-Roda Gauge with a total length of 90 km due to excess flow of 20 million m^3 reveal that dredging is required at some cross sections to maintain the reach and to keep the navigation path sustainable.
13. Hydrodynamics simulation is conducted at Rosetta promontory. Testing several combinations of hard and soft protection measures using the Coastal Modeling Software system is performed. It is concluded that optimum solution is to use a combination of an eastern jetty of 360 m length and western jetty of 800 m, in addition to sand nourishment (with amount of 300,000 and 200,000 m^3) in front of the eastern and western revetment, respectively. The chosen scenario has the merits of (a) the sand nourishment will be added every 2 years for the western part and every year for the eastern side; (b) an annual dredging work of 36,000 m^3 behind the eastern jetty is required; (c) the construction cost is estimated to be about \$9,920,000 while the annual maintenance cost for the sand nourishment is estimated to be about \$2,700,000 every year for the eastern part of the promontory and about \$1,800,000 for the western part. (These costs are calculated based on a currency change rate of \$1 = EGP8).
14. The study of ecosystem and biodiversity in the Nile Basin indicated that the Nile Basin countries face several problems including (but not limited to)

inefficient water use, water pollution, population stress and land degradation, deforestation and soil loss, over hunting, and fishing and sedimentation problems. Also, the study concluded that the main sources of biodiversity degradation in Lake Nasser include the development of land around the lake, expansion of agricultural land, and disappearance of habitat from excessive grazing or application of agrochemicals. Also, it is concluded that habitats are affected by pollution, and hunting, fishing, and tourism activities are disturbing the natural habitat especially within the shoreline zone.

15. The biggest challenges and threats facing fisheries resources in the Nile Basin include species introductions; degradation of aquatic habitats and biodiversity; unsustainable fishing practices; pollution and eutrophication resulting from human populations and invasive weeds. The constraints that hamper the development of aquaculture in Africa, including Nile Basin countries are introduced. Management plans and necessary measures are suggested in the chapter titled fish and fisheries, and the implemented efforts to develop the industry are presented.
16. Considering the Blue Nile watershed hydrological modeling, the use of GSMAP_MVK rainfall data set underestimates considerably annual precipitation and seasonal precipitation as well due to missing data values which could be substituted by TRMM (GSMAP_MVK_T) data to provide comparable performance to other satellite-based products, with a slightly better probability of detection during the flood season. Moreover, the performed statistical analysis of annual and seasonal rainfall of 22 ground-based meteorological stations in the upper Blue Nile River basin for 49 years indicated that a mix of insignificant positive (increasing) and negative (decreasing) trends in seasonal, and annual rainfall at the stations is identified. Generally, out of the 22 stations surveyed, significant trends in annual series are evident only at one station at the rate of -2.9 mm/year, and the significant decreasing trend in rainy seasonal series at the same station was at the rate of -1.9 mm/year.
17. Rainfed agricultural production systems and irrigated agriculture are the two main irrigation and production systems in the Nile Basin. The former is vulnerable to impacts of climate variability and change and is characterized by subsistence production, and low inputs and yields. The latter, in particular on a commercial scale, has high productivity and improved water-use efficiency, but there are some schemes in the Basin where yields are still low. Intra-basin trade in agricultural products has the potential to promote rural development, enhance regional food security, and foster regional integration. However, trade volumes in primary agricultural commodities between Nile Basin countries are low because none of the riparian countries produces sufficient surplus to sustain high-volume intra-basin trade. The opportunity for enhancement of regional integration through trade, therefore, remains largely unutilized, despite the improving climate for regional trade brought about by the creation of regional trade bodies such as EAC and COMESA [1].
18. Expected shortage of water due to the construction of GERD affects greatly the irrigated agriculture system in Egypt. In general, the construction of Upper Nile

mega projects like GERD will cause a shortage of water at Egypt side leading to total environmental negative impacts. Consequently, the impacts of the water scarcity at Egypt include crop and fish production and farmers income, present and future reclaimed land (other developments), salt water intrusion, soil salinity, supply intakes and intakes for water treatment plants, main canals and rayahs, ecological imbalance, tourism industry, health risks, generation of hydropower, Dam failure impacts, and socioeconomic impacts. The large capacity of GERD reduces the ability of the High Aswan Dam as a long-term storage reservoir as indicated by the increase in water deficit quantity and frequency. The filling of GERD will have very significant negative impacts on the Egyptian water and energy sectors depending on the adopted reservoir filling rule, and GERD dam size and the incoming flow during the flood season.

19. A recent study conducted by Batisha [2] proved that using the Rapid Impact Assessment Matrix (RIAM) technique "indicates that in both Physical and Chemical category and Biological and Ecological category, there are major negative impacts for both upstream and downstream countries. On the other hand, the RIAM indicates that in the Sociological and Cultural category and Economic and Operational category will have a positive impact in upstream countries and negative impacts in downstream countries" [2].
20. On the other hand, the review of the effects of climate change on the Nile Basin revealed that (a) short-term (seasonal or shorter) droughts are expected to intensify in most of Nile basin regions. Longer-term droughts are expected to intensify in large areas of the eastern Nile; (b) annual precipitation and river-flow increases are observed in the west of the delta and the Northwest regions. Very heavy precipitation events have increased nationally and are projected to increase in all regions as a result of Extremes' events. However, the length of dry spells is projected to increase in most areas, especially the eastern portions of the Basin; (c) "climate change is expected to affect water demand, ground-water withdrawals, and aquifer recharge, reducing groundwater availability in some areas" [3] especially at Egypt Nile valley and delta; (d) climate change affects water demand and the ways water is used within and across regions and economic sectors. Egypt and Sudan are particularly vulnerable to changes in water supply and demand due to climate changes and potential development project at the Blue Nile and (e) "changes in precipitation and runoff, combined with changes in consumption and withdrawal, have reduced the surface and groundwater supplies in many areas. These trends are expected to continue, increasing the likelihood of water shortages for many uses" [3]. Recently, Elkolally et al. [4] indicated that the Eastern Nile Basin "received several drought events during the long rainy season (June to September) and the short rainy season (March to May) as well. Annual analysis of SPI time series indicated that the study area received several drought events, and the most severity event was during the year 1984."
21. Climate change could have very serious impacts on growth and development. The costs of stabilizing the climate are significant but manageable; delay would be dangerous and much more costly. Factors like climate change impacts, many

institutional, scientific, economic, and political barriers present challenges to implementing adaptive strategies. Also, non-climate-related stresses that contribute to existing vulnerabilities should be reduced as it can be an effective approach to climate change adaptation.

22. The Nile Basin is also prone to severe inter- and intra-annual variability of rainfall. The basin's population is expected to double every 25 years. High population growth and increased variability of rainfall are forcing many of the countries, which depend on rain-fed agriculture, into irrigated farming system, thus increasing overall consumptive water demand on the system.
23. The analysis of legal and international laws shows that the principle of fair and just use of the international waterways is the most appropriate legal principle internationally. It is also the best that is suitable for the nature of the international rivers because it considers the differences among the onshore states as far as their water needs, their population, the degree of their economic and social progress are concerned. Also, the absence or presence of river fresh waters alternatives should be considered. However, the debate remained in many cases among the onshore states located on the banks of the same international river although they recognize the principle of fair and just use.
24. The conducted analysis on the Nile, an international river is based on (a) the agreement of 1978 regarding the international succession of the treaties, (b) Vienna Convention regarding the laws governing the agreements (1969), and (c) the basics of the African actions adopted since the establishments of the Organization of African Unity in relation to the recognition of the inherited borders – including the disadvantages – in order to maintain the stability of the international relations, security, and peace in the continent. Therefore, the analysis proved the accuracy of the Egyptian/Sudanese position legally. Egypt and Sudan adhered to the desire that the agreement should include a provision that would ensure the historical and acquired rights, guaranteed by the law which is already present in the existing agreements. They agreed that expressing those rights should be under the term "current uses." They also adhered to the principle of prior notification about the projects which upstream states plan to execute, a stable and fixed principle according to the actions, jurisprudence, and laws.
25. Depending on reading the scenarios of the hydropolitical relations in the Nile Basin, the analysis clarifies that the conflicting interactions would be increased in the area due to one or more of the following variables: (a) the insistence of the upstream states on the Entebbe Framework Agreement as a legal framework, (b) the execution of dams and projects in the Nile upstream states without prior consultation, and (c) the refusal of the Republic of South Sudan to the Agreement signed by Egypt and Sudan in 1959 and the increased external interventions that stimulated conflict.
26. On the other hand, it is anticipated that the cooperative tendency regarding interactions among the Nile Basin states will increase due to one or more of the following variables: (a) the establishment of collective developmental projects, (b) the resurrection and activation of the Nile Basin Initiative, and (c) the

activation of water diplomacy between Egypt and the Nile Basin states and the activation of the people's diplomacy.

27. To conclude, the weighting scenario remains subject to the will of the people and the states of the Nile Basin. Also it depends on the rational choice and the trade-offs between the alternatives: managing the conflicts or managing the cooperation on water in a promising area.

3 Recommendations

The following recommendations are stated to help Egypt taking utmost care of its water supply to ensure

1. A significant amount of water could be harvested and added to the net Nile water discharge via efficient and well-managed cooperation between Nile Basin countries. This might minimize or prevent any conflicts between the Upper and Lower Nile stream countries and meets the demand of the high population growth in all Nile basin countries. By the year 2050, the population might reach more than 850 million capita and will certainly cause much pressure on the Nile water quantity and quality.
2. It is highly recommended to conduct a hydrodynamic study to investigate the change in the sedimentation patterns of the AHDR due to different scenarios of sediment concentrations of the incoming flow after the complete construction and operation of GERD.
3. A spatial change in water quality and trophic status is noticed due to the spatial, morphological, and hydrological characteristics of the AHDR. Therefore, it is recommended that the different zones of the AHDR should be assigned to different water uses based on comprehensive water quality studies.
4. It is highly recommended to use the satellite remote sensing and GIS approach to monitor or change detection and estimate the amount of accumulated sediment in the lakes based on building an accurate 3-D model for the lakes.
5. Updating the rating curves for the dams' reservoirs is highly recommended whenever new reliable observations are available. Moreover, "Egypt has to be prepared to significantly improve management of Lake Nasser, it's only major water storage infrastructure" [5]. At the same time "Water-use efficiency in domestic, industrial, and agricultural sectors can be very significantly improved with existing knowledge, technology, and management practices" [5].
6. A future morphodynamic investigation to the first and second reaches of the Nile River (from Aswan to Esna Barrages and from Esna Barrages and from Naga Hammadi Barrages) to understand the mechanism of the increase in the islands surface areas and to understand the mechanism of the sedimentation process through the river banks. Also, it is highly recommended to conduct the same study on other reaches along the Nile River as pre-investigations for future studies on the improvement and sustaining of the navigation paths/ requirements through the Nile.

7. When modeling the bed morphology of the Nile River, a stochastic model like Monte Carlo simulation is needed to run to assess the uncertainty of the results of the 2-D modeling.
8. The distribution of the natural radioactivity in the sediments of the Nile River from El-Minia to the Mediterranean Sea needs to be investigated to complete the picture of the spatial distribution of the natural radioactivity along the Nile.
9. The results of investigating the water and sediment quality from the downstream of Aswan high dam to Assiut indicate that the study should be extended to all sites along the Nile up to the northern coast.
10. Continuous monitoring of the cross sections along the Nile River is needed to measure water levels and velocity pattern and observing the morphological changes in the reach (if any) and consequently updating the hydrodynamic simulation for the different reaches once a new updated data set is available or a change in the morphology is observed.
11. Future research work should move forward towards investigating the use of ecological and environmentally friendly protection methods to sustain the dynamic stability of Rosetta and Damietta promontories. Also, ecological-environmentally-friendly shore protection methods should be adopted whenever possible along the northern coast of Egypt for sustainability of the shoreline in the future.
12. Regular and continuous monitoring scheme for developing ecosystems of the Nile River system is needed. Environmental law should be modified and enforced to prohibit the discharge of wastewater such as agricultural, domestic, industrial, or other sources to the Nile River system. At the same, treatment plants should be constructed (whenever possible) and well operated with high performance at all point source pollution. Also, cooperation in scientific and environmental monitoring of water quality and sources of pollution in African countries should be implemented since any contamination in any upstream country of the Nile basin will affect some or all of the downstream countries. The possible risks of fish cages on the water quality of Nile River and its branches should be assessed, and then the regulations and law should be implemented if any violation exists.
13. Studying the fish and fisheries along the Nile Basin identified a list of constraints that hamper the development of the fish industry. Those constraints should be addressed by Nile Basin States, both individually and cooperatively if aquaculture is to be developed sustainably. The international organizations and fund providers associated with aquaculture development (such as FAO, EU) should also provide more assistance to overcome the listed constraints and to promote aquaculture development in the region. Among the needed actions to sustain the fish industry the following are important: (a) set up and enforce appropriate laws; (b) regulations and policies to sustainably manage the fisheries resources and their habitats in the Nile Basin; (c) develop efficient and effective institutions and institutional processes and governance which involve stakeholders in planning and implementation; (d) develop sustainable funding mechanisms for implementing fisheries programs; and (e) provide adequate

financial resources and human capacity to implement fisheries management program.

14. The hydrological modeling of Nile Basin watersheds needs ground measurements to calibrate the available remote sensed data which has long temporal coverage and can be used for hydrologic modeling purpose. It should be emphasized that a comprehensive study should be conducted to identify the trend and the pattern of the global data and the extent of agreement with the local data to set a suitable adjustment mechanism to the global data sets to suitably integrate them with the local data sets.
15. Concerning the agricultural productivity across the Nile Basin countries, "it is recommended that the Nile countries should implement a coordinated set of measures targeting the multiple constraints affecting the agricultural production sector" [1], which include: (a) Floods and failing rains; (b) Vigorous weeds; (c) High disease and pest prevalence; (d) High cost of farm inputs such as fertilizer and pesticides; (e) High post-harvest losses; (f) Weak extension services; (g) Lack of credit; and (h) Inadequate information on market opportunities.
16. From a water management perspective, the critical interventions in the Nile Basin should include: (a) Increasing investment in irrigation development such that in the downstream countries, focus should be on improving water-use efficiency, while in the upstream countries it should concentrate on improving efficiency of existing irrigation systems and expand the land under irrigation [1]; (b) Improving scheme management and agricultural productivity within the smallholder irrigation schemes in the downstream countries so as to double or triple the agricultural production without additional water demands; (c) Increasing investment in rainwater harvesting and in small-scale irrigation in upstream countries to increase the resilience of rainfed agriculture to climate-related shocks; (d) "Increasing investment in watershed management in upstream countries to reduce soil erosion and to increase water availability, especially in mixed highland smallholder subsistence farming systems; and (e) As production rises and agricultural commodity trade within the region continues to benefit from progressive reduction in tariffs, the struggle to increase trade should shift to deal with the many non-tariff barriers between countries" [1].
17. The entire system of the Nile River Basin should be studied to examine whether the proposed agricultural and hydropower projects can be established together. Also, the needs for development in the entire basin and water scarcity conditions highlighted the need to harvest the vast amount of water losses occurring in the wet (swampy) areas of the Nile River basin to reduce the food gap and promote development in all Nile Basin countries.
18. The study of the effects of the upper Nile mega projects on Egypt justified the apprehension that Egypt has adverse impacts of unilateral development in upstream countries. Therefore, the general international rules of win-win, no harm, and no regret are the only way for regional development for the interest of all Nile Basin countries.

19. Proactively preparing for climate change can reduce impacts while also facilitating a more rapid and efficient response to changes as they happen. Such efforts are beginning at different nations in Nile basin to build adaptive capacity and resilience to climate change impacts.
20. Increasing resilience and enhancing adaptive capacity in most of the Nile Basin are needed. Water resources managers and planners should seek new innovative strategies to be ready to manage the new risks, vulnerabilities, and opportunities that might not be adequately managed within existing practices.
21. Review and analysis of climate change impacts across the Nile Basin indicate that proper mitigation and adaptation actions are required across all Nile basin countries, and it needs not cap the aspirations for growth of rich or poor countries. Therefore, climate change demands an international response, based on a shared understanding of long-term goals and an agreement on frameworks for action. "Three well-respected global circulation models indicate flow increases of 12 and 18% and catastrophic decline of 77%. Under such uncertainties, Egypt needs to increase all types of water storage, improve water use efficiencies significantly in all sectors, and monitor river flow changes over the years very carefully" [5].
22. Evidence indicates that cooperative development of the basin's water resources would lead to more efficient and sustainable development of the basin's water sources. Therefore, a regional system to apply an integrated water resources management in Nile Basin countries' water policies is highly needed.
23. It is highly required to have a shared knowledge base, analytical capacity, and supporting stakeholder interaction to ensure cooperative planning and management decision making for the Nile River Basin sustainable management of its natural resources to be included into national, economic, and sustainable development policies.
24. The achievement of the sustainable development of any Nile Basin state should be encouraged as long as it causes no harm to the Nile onshore states. Therefore, consultation and prior notification must be adopted by the upstream states if they seek to implement any development project (such as construction of dams) to avoid any harm that may affect the quantity and quality of the current water share to the downstream countries.
25. The efforts of the upstream countries should be employed to secure the benefits of the Nile Basin communities via mutual projects that can help achieving the requirements of the principle of equitable and reasonable use without causing any harm to the downstream countries instead of focusing on attempts to change the legal amounts of the downstream countries.
26. It is highly recommended that the Nile Basin countries should go to manage the cooperation instead of going to manage the conflicts for the benefits of all of them. Other external countries (non-Nile Basin) should enforce any real cooperation trend and respect the real willingness of the Nile Basin countries regardless of their strategic issues in the region.
27. The increasing demand of water by Egypt due to the increase in the population necessitates that Egypt should give considerable attention to the water supply

issue during the next few coming decades. "Ensuring water security in Egypt in the coming decades means that the country will have to run ever faster and faster simply to remain in the same place" [5].

Acknowledgement The writer of this chapter would like to acknowledge the participation of all authors who contributed to this volume of "The Nile River" and made it a reality. Also, great thanks and appreciation are due to Prof. Andrey Kostianoy, the series, for his continuous support and help whenever needed. All thanks are due to the Springer team members for their great effort and support to produce the volume with the highest possible quality.

References

1. NBI (2012) State of the river Nile Basin 2012. http://sob.nilebasin.org/inner.php#!/chapter_9. Accessed 8 Mar 2017
2. Batisha AF (2015) Sustainability assessment in transboundary context: Grand Ethiopian Renaissance Dam. Model Earth Syst Environ 1:36. Springer, Cham. Doi: 10.1007/s40808-015-0033-2
3. National Climate Assessment (2014) http://nca2014.globalchange.gov/highlights/report-findings/water-supply. Accessed 8 Mar 2017
4. Elkollaly M, Khadr M, Zeidan B (2017) Drought analysis in the Eastern Nile basin using the standardized precipitation index. Environ Sci Pollut Res. Springer, Berlin. Doi: 10.1007/s11356-016-8347-9
5. Biswas AK (2016) Lake Nasser: alleviating the impacts of climate fluctuations and change, Chapter 11. In: Tortajada C (ed) Increasing resilience to climate variability and change, Water resources development and management. Springer, Singapore. Doi: 10.1007/978-981-10-1914-2_11

Erratum to: Estimating the Sediment and Water Capacity in the Aswan High Dam Lake Using Remote Sensing and GIS Techniques

Abdelazim Negm, Mohamed Elsahabi, and Sommer Abdel-Fattah

A.M. Negm (ed.), *The Nile River*, Hdb Env Chem, DOI 10.1007/698_2016_109,

Erratum to: Hdb Env Chem
10.1007/698_2016_109

For this chapter, the following belated corrections were received from author:

1. The paragraph "The results indicate that the method used by AHDA underestimates the sedimentation capacity by about 4%" in **Abstract** section should be replaced by "The results indicate that the present approach overestimates the sedimentation capacity by about 4.3% compared to the results of the method used by AHDA".
2. The paragraph "This means that the method used by AHDA underestimated the sedimentation capacity by about 4%." in section **5.7 Application and Comparisons** should be replaced by "This means that the present approach

The updated online version for this chapter can be found under DOI 10.1007/698_2016_109

A. Negm (✉)
Water and Water Structures Engineering Department, Faculty of Engineering, Zagazig University, Zagazig 44519, Egypt
e-mail: amnegm85@yahoo.com; amnegm@zu.edu.eg

M. Elsahabi
Civil Engineering Department, Faculty of Engineering, Aswan University, Aswan, Egypt
e-mail: mohamed.sahabi@aswu.edu.eg

S. Abdel-Fattah
McMaster University, Hamilton, ON, Canada
e-mail: abdelfs@mcmaster.ca

A.M. Negm (ed.), *The Nile River*,
Hdb Env Chem (2017) 56: 731–732, DOI 10.1007/698_2017_20,

overestimated the sedimentation capacity by about 4.3% compared to the method used by AHDA".

3. The paragraph "Moreover, results indicate that the method used by the AHDA, based on the complementary cross sections, underestimates the sedimentation amount by about 4% from year 2000 to 2012" in section **6 Conclusions and Recommendations** should be replaced by "Moreover, results indicate that the present approach overestimates the sedimentation capacity by about 4.3% from year 2000 to 2012 compared to the results of the method used by AHDA".
4. Reference "14. Moustafa A (2013) Predicting deposition in the Aswan high dam reservoir using a 2-D model. Ain Shams Eng J 4:143–153" in **References** section should be replaced by "14. Moustafa A (2013) Predicting the deposition in the Aswan high dam reservoir using a 2-D model. Ain Shams Eng J 4:143–153".
5. Reference "37. Elsahabi MA, Negm AM, Ali KA (2016) Possible correlation of 2-D velocity profiles and sediment accumulation for AHDL. In: Nineteenth International Water Technology Conference, IWTC19, Sharm ElSheikh, Egypt" in **References** section should be replaced by "37. Elsahabi MA, Negm AM, Ali KA (2016) Correlating the velocity profiles to the sediment profiles of the active sedimentation zone of Aswan High Dam Lake. In: Proceedings of the nineteenth international water technology conference (IWTC19), Sharm ElSheikh, 21–23 April".

We apologize for any inconvenience caused.

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