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A Micro-level Perspective

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Abstract

This paper analyzes vulnerability to climate change of the farming sector in the Nile Basin of Ethiopia across different agro-ecological zones. We construct composite vulnerability indices, which integrate both the bio-physical conditions of the farming regions and the socio-economic conditions of the farm households to investigate overall vulnerability as well as adaptive capacity, exposure and sensitivity. Concerning overall vulnerability, findings show that, among the four agro-ecological zones considered in this study, the humid lowlands and drought-prone highland areas of the Nile Basin of Ethiopia are the most vulnerable zones. Findings also show that local farming systems where enset is the dominant crop in moisture-sufficient highland areas have the highest adaptive capacity, while the humid lowland zone is the lowest in terms of adaptive capacity to climate change. Regarding exposure and sensitivity, the drought-prone highland areas are the most exposed and most sensitive to climate change. The moisture-sufficient highland areas tend to be the least exposed and sensitive zones, even though population density is highest and the precipitation amount is declining over time. Findings imply that climate change adaptation should be placed within the broader context of development strategy and rural poverty reduction.

Key Words: climate change, vulnerability, agro-ecology, Nile Basin, Ethiopia

JEL Codes: Q18, Q54

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1. Introduction

This paper analyzes vulnerability to climate change of Ethiopian farmers across different agro-ecological zones by constructing composite vulnerability indices, which integrate both the biophysical conditions of the farming regions and the socioeconomic conditions of the farm households. Findings show that, among the four major agro-ecological zones in the Nile Basin of Ethiopia, the humid lowlands and drought-prone highland areas are the most vulnerable zones. Findings also show that *enset*-based farming[1] (a local farming system where *enset* is the dominant crop) in moisture-sufficient highland areas has the highest adaptive capacity, while the humid lowland zone is the lowest in terms of adaptive capacity to climate change.

Vulnerability and adaptation options to climate change in Africa and other developing countries have received increasing attention. In particular, Africa is viewed as the most vulnerable region to climate variability and change. Africa is characterized by nature-dependent livelihoods, indicating that the continent is disproportionally hit by adverse effects of climate change. For instance, IPCC (2007) argued that climate change is expected to expose between 75 and 250 million people to water stress by 2020. In addition, by 2020 there will be a significant reduction in arable land and, in some African countries, yields from rainfed agriculture will decline by as much as 50%, which worsens

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[1] *Enset* (i.e., Enset ventricosum) is an edible crop (plant). It is the edible species of a separate genus of the banana family, thus named "false banana," but the enset fruit is not edible. Enset is a genus of monocarpic flowering plants native to tropical regions of Africa and Asia. It is also common in southern parts of Ethiopia. The plant is cut before flowering, the pseudostem (false stem) and leaf midribs are scraped, the pulp is fermented for 10-15 days and finally steam-baked flat-bread is prepared out of it and used as food (Shank and Ertiro 1996). An enset-based farming system is where enset is the dominant crop but other crops such as cereals (maize or sorghum) and tuber crops (potatoes and sweet potatoes) are also grown (Brandt et al. 1997). The cereal-based system is different from the enset-based system in that cereals such as teff, wheat and barley are the dominant crops grown.

food insecurity and malnutrition. Vulnerability of a country or region to climate change depends both on its socioeconomic development and on environmental factors (Kelly and Adger 2000; McCarthy et al. 2001). The extent of vulnerability to risks of climate change is also exacerbated by the interaction of multiple stresses that occur at various levels, limited adaptive capacity and constrained choice of adaptation options of most households in rural Africa (Boko et al. 2007).

With a population of over 90 million (UN 2013) Ethiopia is the second most populous country in Africa. Ethiopia has witnessed double digit and broad based economic growth (averaging about 11% growth in real GDP per year), compared to the regional average of about 5 % over the past decade (World Bank 2014). This economic growth is contributing to poverty reduction and progress toward achieving the Millennium Development Goals. However, the country has been experiencing more frequent and recurrent droughts since the 1980s, with a declining average daily precipitation rate and a rising average temperature (World Bank 2007). Over the coming decades, frequency of droughts is projected to increase (Oxfam 2009). This means that Africa’s population is highly vulnerable to climate change because the majority (about 80%) are rural dwellers engaged in rainfed agriculture. The limited economic resources, low literacy level, limited technology and infrastructure, high level of poverty, limited/lack of specialization in cash-yielding activities, etc. also confound their adaptive capacity and exacerbate their degree of vulnerability to climate change, although these are improving. Consequently, this paper’s examination of different zones, in order to identify the most vulnerable areas of the country, is particularly relevant for the design and targeting of policies aimed at enhancing proactive adaptive capacity such as planned adaptations.

Some studies have examined households’ vulnerability to climate change across regional states and in the Nile Basin of Ethiopia (Deressa et al. 2008a; 2008b) and others analyze determinants of households’ choice of adaptation options (Deressa et al. 2008b; 2008a; Di Falco and Veronesi 2014; Di Falco et al. 2012; Kabubo-Mariara and Karanja 2006). Some attempts also have been made to identify the economic aspects, including the economy-wide impact of climate change in Ethiopia using a Ricardian approach and CGE model (Deressa 2007; Yesuf et al. 2008; Mideksa 2010; Deressa and Hassan 2009; Gebreegziabher et al. 2015; 2013). Similarly, some studies have been carried out on vulnerability and adaptation to climate change in other Sub-Saharan African (SSA) countries such as Lesotho (Ziervogel and Calder 2003), South Africa (Nhemachena and Hassan 2007; Stringer et al. 2009), Tanzania (Paavola 2004), and the Sudan (Osman-

Elasha et al. 2006). Such studies also include comparison of vulnerability and adaptation to climate change across countries, such as comparisons between Ethiopia and South Africa (Bryan et al. 2009) and Kenya and Tanzania (Eriksen et al. 2005).

Though these studies provide some useful insights in the area of vulnerability to climate variability and change and possible adaptation options, and reflect the current efforts to understand the relationship between climate change and vulnerability, most of them are at the aggregate level and hence have little policy relevance at the micro-level. Except for Deressa et al. (2008a), which attempted to construct an overall vulnerability indicator at regional levels, no study has examined climate change vulnerability by constructing indices at the micro-level in Ethiopia. Thus, the aim of this paper is to fill this gap through assessing the levels of vulnerability to climate change of different agro-ecological zones of Ethiopia, taking the Nile Basin region as a case study. The objectives of this study are twofold: first, to construct individual vulnerability indices; and, second, to assess overall vulnerability and compare the extent across different agro-ecological zones.

Assessing and measuring vulnerability are key to figuring out which places and people are the most vulnerable, as well as the degree of vulnerability and possible adaptation options. More specifically, vulnerability assessment helps to set three policy measures. First, it is used to specify long-term targets for mitigation of climate change; second, to identify vulnerable places and people and to prioritize resource allocation for adaptation; and, finally, to put forward specific adaptation recommendations for specific places and groups (Füssel and Klein 2006). Thus, this work fits with the ongoing use of vulnerability assessments across policy areas, including famine early warning (USAID 2007), food insecurity (WFP2004), poverty, health and globalization (O'Brien et al. 2004; UNEP 2004).

The rest of paper is organized as follows. The next section reviews climate change hotspots and vulnerability. Section 3 presents the conceptual framework. Section 4 presents the empirical method (model) employed in the study, while Section 5 presents results and discussion. Finally, the paper concludes and draws implications.

2. Climate Change Hot Spots and Vulnerability: Review of Literature

Developing countries in general and Africa in particular are highly vulnerable to climate variability and change. According to IPCC, "Africa is one of the most vulnerable continents to climate change and climate variability" (Boko et al. 2007). Within Africa, countries like Ethiopia, with low levels of economic development, inadequate infrastructure and lack of institutional capacity, are more vulnerable to climate change (Admassie and Adenew 2008). Among African dwellers, people living in arid and semiarid, low-lying coastal and water-limited or flood-prone areas are particularly vulnerable to climate change (Watson et al. 1996). Arid and semiarid systems and coastal areas in the East African countries are among the most vulnerable parts of SSA (Thornton et al. 2008). Economic sectors and ecosystem services that are highly vulnerable to the effects of climate change include agriculture, fishery, water and forests. Mendelsohn et al. (2016) document the negative consequences of severe warming on ecosystems in Africa.

Other scholarly studies on climate change hot spots vulnerable places and people in SSA include Barrios et al. (2010); Dell et al. (2008) and Vincent (2004). Dell et al. examine the impact of climatic changes on economic activity throughout the world. They find that higher temperatures substantially reduce economic growth in poor countries but have little effect in rich countries. Moreover, higher temperatures appear to reduce growth rates in poor countries, rather than just the level of output. In addition, higher temperatures have wide-ranging effects in poor nations, reducing agricultural output, industrial output, and aggregate investment, and increasing political instability. Barrios et al. investigate the role of rainfall trends in explaining the poor growth performance of sub-Saharan African nations as compared to other developing countries. They find that rainfall has been a significant determinant for the poor economic growth in Africa, but not for other developing countries. They argue that, had it not been for rainfall decline, today’s gap in African GDP per capita relative to the rest of the developing world could have narrowed by a magnitude of around 15 to 40 per cent. Vincent (2004) creates an index to empirically assess relative levels of social vulnerability to climate change-induced variations in water availability and to allow cross-country comparison in Africa. Results shows current vulnerability to climate change-induced changes in water availability puts Niger, Sierra Leone, Burundi, Madagascar, Burkina Faso and Uganda as the most vulnerable countries in Africa, whilst Djibouti, Mauritius, Algeria, Tunisia, South Africa and Libya are the least vulnerable. In eastern Kenya, people living in the dry lands are highly vulnerable to climate extremes such as drought.

Adaptation to climate variability is exacerbated by limited access to natural resources and infrastructures (Owuor et al. 2005). Thus, poor and marginalized groups are more vulnerable to climate change and their adaptation options are constrained by social setting and access to resources. Thornton et al. (2008) argued that such households have limited adaptive capacity and hence are highly vulnerable to the adverse effects of climate change. Gbetibouo (2009) emphasize that household size, farming experience, wealth, access to credit and water, and off-farm activity diversification affect adaptive capacity to climate change in the Limpopo river basin of South Africa. Climate change vulnerabilities are severe in food insecure parts of Zambia (Thurlow et al. 2009). In Lesotho, marginalized social groups in terms of resources, infrastructure and information access are more vulnerable to climate change (Ziervogel and Calder 2003). Household-level evidence from Kenya and Tanzania reveals that individuals who are engaged in many activities at low intensity are more vulnerable than individuals specialized in one favored activity. In these two nations, household coping options are constrained by access to resources and infrastructure (Eriksen et al. 2005). Using a livelihood vulnerability index, Hahn et al. (2009) found that various regions in Mozambique have different levels of vulnerability and hence proposed different adaptation options.

According to Gbetibouo and Ringler (2009), vulnerability to climate change and variability is intrinsically linked with social and economic development. Provinces with high levels of infrastructure development, high literacy rates, and low shares of agriculture in total GDP are relatively low on the vulnerability index. In contrast, the highly vulnerable regions are characterized by densely populated rural areas, large numbers of small-scale farmers, high dependency on rainfed agriculture and serious land degradation. In addition, households with limited fixed assets such as livestock and households that depend on rainfed agriculture are more vulnerable to climate change (Shewmake 2008). Deressa et al. (2008b) also find that the degree of vulnerability varies across regional states of the country, with relatively less-developed, arid and semiarid regions (Afar and Somali) being highly vulnerable to climate change. Drought-prone regions such as Oromia in Ethiopia’s eastern and lowland areas and Tigrai are also highly vulnerable to climate change. Deressa at al. (2008a) measure the vulnerability of farmers to climatic extremes such as droughts, floods and hailstorms, by employing the “vulnerability as expected poverty” approach in the Nile Basin of Ethiopia. Their results show that farmers’ vulnerability is highly sensitive to the minimum daily requirement for survival (or poverty line) in the area. The results further indicate that farmers in *kola* agro-ecological zones (which are warm and semi-arid) are the most vulnerable to extreme climatic events.

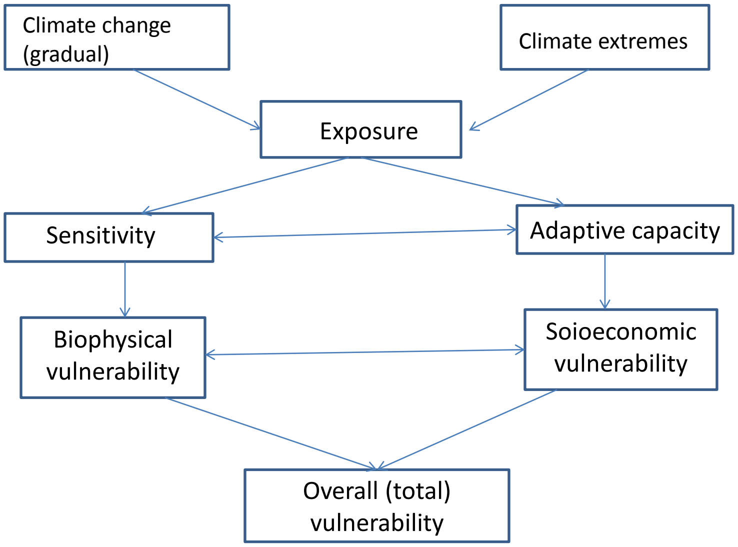
In climate change literature, two components of vulnerability are identified: internal and external dimensions. The internal dimension refers to frailty, insecurity and capacity to anticipate, cope with, resist and recover from adverse effects of shocks. The external dimension involves exposure to risks and shocks. However, in its Second Assessment Report, IPCC defined vulnerability as the degree to which climate change may cause damage to a system and noted that the level of vulnerability depends on the sensitivity of the system to shocks and its ability to adapt to negative impacts of climate change (Watson et al. 1996). At the time of the Second Assessment Report, the report changed its focus concerning vulnerability from internal and external dimensions to sensitivity and adaptive capacity. It is argued that vulnerability to climate change is severe where a system is highly sensitive to climate change and adaptability is the lowest. The IPCC Third Assessment Report (TAR) reconciles both sides by adding a third component to vulnerability, defining it as: *"The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity"* (McCarthy et al. 2001). According to this definition, vulnerability includes an external dimension that is represented by the exposure of a system to climate variations, as well as a more complex internal dimension comprising its sensitivity and adaptive capacity to these stressors (Füssel and Klein 2006). The IPCC Fourth Assessment Report (AR4), which reports recent advances in climate change, contains a vulnerability definition consistent with that of the Third Assessment Report (IPCC 2007). Under this framework, a highly vulnerable system would be one that is very sensitive to modest changes in climate, where the sensitivity includes the potential for substantial harmful effects, and for which the ability to adapt is severely constrained. Hence, vulnerability is a function of three components: exposure, sensitivity and adaptive capacity, which are influenced by a range of physical, environmental, and socioeconomic and political factors.

A common thread in the climate change impacts and vulnerability literature is that countries, regions, economic sectors and social groups differ in their degree of vulnerability to climate change (Bohle et al. 1994). Similarly, in vulnerability analysis, poverty and inequality are key factors, as inequality and marginalization are important determinants of the degree of vulnerability to climate change (Ribot 1996). Thus, it is paramount to focus on the poor people in developing countries rather than emphasizing poor countries themselves.

3. Conceptual Framework

Different international organizations define vulnerability in various ways. Definitions of vulnerability by the Intergovernmental Panel on Climate Change (IPCC) are related specifically to climate change. Vulnerability to climate variability and change can be defined in several ways as pre-adaptation and post-adaptation (end point) vulnerability, outcome vulnerability and conceptual vulnerability. According to the post-adaptation definition, vulnerability refers to the residual impacts of climate change after adaptations options have been taken into account. That is, "the level of vulnerability is determined by the adverse consequences that remain after the process of adaptation has taken place" (Kelly and Adger 2000). This approach specifically focuses on the physical dimensions of vulnerability. The pre-adaptation (or starting point) definition of vulnerability has its origin in the literature on food security and famine (Bohle et al. 1994) and vulnerability to natural hazards (Blaikie et al.1994). According to this approach, limited access to resources and political instability and exposure are the main cause of vulnerability. However, in this study we adopt the definition of the IPCC Third Assessment Report (IPCC 2001), which defines vulnerability as a function of three dimensions: sensitivity, exposure and adaptive capacity.

Figure 1. Conceptual Framework for Vulnerability Analysis



Source: Adapted from Deressa et al. (2008a).

Figure 1 above provides the conceptual framework for analyzing vulnerability. As the figure illustrates, our study context could be viewed as exposed to both gradual climate change (top left corner of Figure 1), mainly involving change in temperature and precipitation, and climate extremes (top right corner of Figure 1), such as drought (von Braun and Webb 1994) and flood (World Bank 2008). Exposure in turn affects sensitivity, i.e., exposure to higher frequencies and intensities of climate risk seriously affect economic and social outcomes such as crop yield, income and health. Exposure is also related to adaptive capacity. Specifically, higher adaptive capacity either reduces the potential damage from or provides resilience against exposure to higher climate risk.

This conceptual framework for vulnerability also suggests that sensitivity and adaptive capacity are interlinked. That is, given some fixed level of exposure, adaptive capacity influences the level of sensitivity. Lower adaptive capacity results in higher sensitivity and vice versa. Hence, sensitivity and adaptive capacity together with exposure add up to overall (total) vulnerability. The conceptual framework also captures socioeconomic vulnerability, which mainly deals with variations within a society (Adger 1999), and biophysical vulnerability, which emphasizes the adverse effects of environmental factors on human and natural systems (Füssel and Klein 2006). We employ the integrated approach, which tries to integrate both biophysical and socioeconomic factors in analyzing vulnerability to climate change (Füssel 2007).

3.1 Adaptive Capacity

The IPCC (2001) describes "adaptive capacity" as the potential or ability of a system, region, or community to adjust to the effects or impacts of climate change (including climate variability and extremes).[2] Adaptive capacity is a context-specific concept and can vary from country to country, from community to community, among social groups and individuals, and over time (IPCC 2001; Smith and Wandel 2006). Besides, according to McCarthy et al. (2001), adaptive capacity is considered "a function of wealth, technology, education, information, skills, and infrastructure, access to resources, and stability and management capabilities." Therefore, analyzing vulnerability must involve identifying not only the threat, but also the "resilience,"[3] or the potential

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[2] For example,communities may rely on informal non-monetary arrangements and social networks along with livelihood diversification and financial remittances through extended family networks to cope with shocks such as drought and storm damage (Adger 2001; Barnett 2001; Sutherland et al. 2005; Yilma et al. 2012).

[3] Though it can be envisaged that they are interrelated, it is important to note that the terms "vulnerability" and "resilience" are not one and the same. "Vulnerability" is essentially pre-event, inherent characteristics of a system (social or natural) that create the potential for harm, whereas "resilience" is the ability of a social system to respond to and recover from disasters (Colburn and Seara 2011).

responsiveness of the system and its ability to exploit opportunities and resist or recover from the negative effects of a changing environment. The means of resilience could be the assets and entitlements that an individual, a household, or a community can mobilize and manage in the face of hardship. It should also be noted that there are close linkages between vulnerability and livelihoods, and thus building resilience is a question of expanding and sustaining these assets (Moser 1998). Put differently, vulnerability is envisaged to be closely linked to asset ownership. The more assets people have, the less vulnerable they are; conversely, the greater the erosion of people's assets, the greater their vulnerability (insecurity).

Following Gbetibouo and Ringler (2009), in this study, we postulate that adaptive capacity is explained as dependent upon four livelihood assets:

1. Social capital represents social networks as captured by number of *ider*[4] and *iqub;*[5] members in close relationship within the *got*;[6] and number of *debbo* and *jigge*[7] participants in close relationship with the *got.* Social capital is envisaged to have three roles. It can be a means of transferring information about new technology. It also facilitates smoother financial transactions among farmers. In addition, it enables farmers to overcome collective action dilemmas. Therefore, it is hypothesized that social capital positively influences adaptation to climate change.
2. Human capital is represented in the study by the literacy rate among household heads, as well as age and attendance at training. This is envisaged to reduce vulnerability by increasing households' capabilities and access to information and, thus, enhancing households' abilities to cope with climate extremes and variability.
3. Financial capital includes farm holding size, number of livestock (proxied by tropical livestock units or TLU), and whether or not the primary residence is constructed with a metal roof. These are considered indicators of a household's wealth. Households with fewer TLU, smaller farm size and no metal roof are

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[4] Ider is a kind of social network in Ethiopia which operates as a funeral association.

[5] Iqub is a rotating saving and credit network.

[6] Got refers to a group of villages.

[7] Debbo and jigge refer to social networks where people support each other during peak seasons of agricultural activities.

assumed to be less economically sound and this makes them more susceptible to climate change.

4. Physical capital includes variables such as distance to and major source of domestic water, access to extension services and new technologies, and distance to the nearest input and output market. Better access to infrastructure and markets is believed to reduce transaction costs and strengthen the links between input and product markets.
5. The effect of variables such as marital status and gender of the household head are assumed to be indeterminate.

3.2 Exposure

O’Brien et al. (2004) relate exposure to the degree of climate stress affecting a unit of analysis, that is, the magnitude and frequency of extreme events to which a particular area or unit of analysis is exposed. This could be either in the form of long-term changes in climate conditions or by changes in climate variability (IPCC, 2001). In our study, variables such as decadal change in temperature and precipitation are regarded as factors that affect exposure to climate change. We take the base year as 1994/5. It is also assumed that large decadal changes in both temperature and precipitation lead to higher exposure.

3.3 Sensitivity

Sensitivity explains the human and environmental conditions that can either worsen the hazard or trigger an impact (Gbetibouo and Ringler 2009). In this study, we include four factors that may have impact on the sensitivity of farmers in the study area:

Climate extremes: In different parts of the study area, the main constraints of agriculture are drought, famine or hailstorm.

Population density: It is assumed that districts with high population density are more sensitive to climate change, because more people are exposed to climate extremes and variations.

4. Empirical Method and Data

4.1 Calculating the Vulnerability Indices

There are two broad approaches to empirically calculating vulnerability: i) econometric and ii) indicator methods. The former expresses vulnerability as expected poverty, low expected utility and uninsured exposure to risk (Hoddinott and Quisumbing 2003). The latter tries to assess vulnerability by integrating indicators to form a composite index, which can be at a local level (Adger 1999; Hahn et al. 2009), national level (O’Brien et al. 2004) or global level (Brooks et al. 2005). The basic challenge in constructing indices is the lack of standard ways of assigning weight to each indicator. The two most common weighting methods used to combine indicators are equal and unequal weighting schemes. The former method assigns equal weight to each indicator. The latter method assigns different weights to various indicators using expert opinion (Vincent 2007), complex fuzzy logic (Eakin and Bojorquez-Tapia 2008) or a principal component analysis (Easter 1999).

In this study, we use an integrated approach to construct a composite vulnerability index based on principal component analysis (PCA) weighting schemes. An integrated approach is chosen because it incorporates both socioeconomic and environmental factors in assessing vulnerability. Specifically, composite indices have long been used in a wide variety of disciplines to measure complex, multidimensional concepts that cannot be observed or measured directly (Füssel 2007). Their power lies in their ability to synthesize a vast amount of diverse information into a simple and usable form.

Overall vulnerability is calculated as the net effect of adaptive capacity, sensitivity and exposure. Following Moss et al. (2001), we assigned a negative value to sensitivity and exposure, because their impact is assumed to be negative. Similarly, factors which are listed under adaptive capacity are assigned positive signs, on the assumption that people with higher adaptive capacity are less sensitive to damages from climate extremes and variations, keeping the level of exposure constant. Thus we specify overall vulnerability as:

$$\textit{Vulnerability} = (\textit{adaptive capacity}) - (\textit{sensitivity} + \textit{exposure}) \qquad (1)$$

Note that in Equation (1) a higher net value indicates lesser vulnerability and vice versa.

The next step is to attach weights to indicators. The literature suggests three different methods for attaching weights: (i) expert judgment (Brooks et al. 2005; Moss et al. 2001); (ii) arbitrary choice of equal weight (Lucas and Hilderink 2004; O'Brien et al. 2004b; Patnaik and Narayanan 2005); and (iii) statistical methods such as principal component analysis (PCA) or factor analysis (Cutter et al. 2003; Thornton et al. 2006). We use the third method. That is, we use statistical methods (PCA) to generate the weights and we use STATA software to run PCA. Given a set of variables, PCA is a technique for extracting those few orthogonal linear combinations of variables that most successfully capture the common information from a broad set of variables. The linear index of all the variables that captures the largest amount of information common to all the variables is defined as the first principal component of a set of variables (Filmer and Pritchett 2001).

Let us assume that there are a set of Z-variables ($\beta^*_{1j}$to β^*_{zj}) which represent the Z-indicators (attributes) of each agro-ecological zone. PCA starts by specifying each indicator, normalized by its mean and standard deviation.[8] The selected variables are expressed as linear combinations of a set of underlying components for each agro-ecological zone *j*.

$$\begin{aligned} &\beta_{1j}=x_{11}W_{1j}+ x_{12}\, W_{2j}+ \ldots.+ x_{1z}\, W_{zj} \\ &\ldots \qquad\qquad\qquad\qquad j=1\ldots.J \qquad\qquad (2) \\ &\beta_{z1j}=x_{z1}W_{1j}+ x_{z2}\, W_{2j}+ \ldots.+ x_{zz}\, W_{zj} \end{aligned}$$

where the *W*'s are the components and the *x*'s are the coefficients on each component for each variable that does not vary across agro-ecological zones. The solution to the problem is indeterminate because only the left side of each line is observed. PCA overcomes this problem through finding the linear combination of the variables with maximum variance (i.e., the first principal component W_1j) and then finding a linear combination of the variables orthogonal to the first and with maximum remaining variance and so on. Technically, the procedure solves the equations $(\mathbf{R}-\lambda\mathbf{I})v_n=0$ for λ_n and v_n, where **R** is the matrix of correlations between the scaled variables (the β's) and v_n is the vector of coefficients on the *n*th component for each variable. Solving these equations gives the characteristic roots of **R**, λ_n, which are known as eigen values, and their associated eigen vectors, v_n. The final set of estimates is produced by scaling each $\mathbf{v}_n$ so

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[8] For example, $(\beta^*_{1j} - \beta^*_1)/s^*_1$, where β^*_1 is the mean of β^*_{1j} across agro-ecological zones and s^*_1 is its standard deviation.

that their squares sum up to the total variance; this is another restriction imposed to achieve determinacy of the problem.

By inverting the system, which is implied by Equation (2), the scoring factors from the model are recovered. This yields a set of estimates for each of the *Z*-principal components:

$$W_{1j}=a_{11}\beta_{1j}+a_{12}\beta_{2j}+\ldots+a_{1z}\beta_{zj}$$

$$j=1\ldots.J \qquad (3)$$

$$W_{zj}=a_{z1}\beta_{1y}+a_{z2}\beta_{2j}+\ldots+a_{zz}\beta_{zj}$$

where the *a*'s are the factor scores. Therefore, the first principal component, expressed in terms of the variables, is an index for each agro-ecological zone based on the following expression:

$$W_{1j}=a_{11}(\beta^*_{1j}-\beta^*_{1})/(s^*_{1})+\ldots+a_{1z}(\beta^*_{zj}-\beta^*_{z})/(s^*_{z}) \qquad (4)$$

Though our scale of analysis is agro-ecological zone, we also provide the results of district level analysis in the appendices.

4.2 Variables and Hypothesis

As mentioned above, we base our definition of vulnerability on IPCC (2001), where a region's vulnerability to climate change and variability is described by three elements: exposure, sensitivity, and adaptive capacity. In addition, based on an extensive review of previous studies, we identify the indicators of vulnerability components selected and the research hypothesis. In particular, we draw on Aandahl and O'Brien (2001), Moss et al. (2001), Cutter et al. (2000 and 2003), TERI (2003), O'Brien et al. (2004b), Lucas and Hilderink (2004), Brenkert and Malone (2005), Brooks et al. (2005), Patnaik and Narayanan (2005), Thornton et al. (2006), Deressa at al. (2008), Gbetibouo and Ringler (2009), and Hahn et al. (2009). Accordingly, the following indicator variables are considered and corresponding hypotheses (expected signs) are put forward (see Table 1).

Table 1. Components of Indicators of Vulnerability and Expected Signs

Determinants of Vulnerability	Component indicator	Expected sign
Adaptive Capacity	Gender of the hh head	
	Age of the hh head	
	Marital status of the hh head	(+)
	No. of years of education of the hh head	(+)
	Primary residence with metal roof matter	(+)
	Major source of domestic water	(+)
	Distance of water source from home (domestic) in km	(+)
	Have you attended training on crop production?	(+)
	Have you attended training on livestock activities?	(+)
	Do you get advice from extension workers on crop production?	(+)
	Do you get advice from extension workers on livestock activities?	(+)
	Distance to nearest market place for selling products (Hrs.)	(+)
	Distance to nearest market place for obtaining inputs (Hrs.)	(+)
	Total area of farmland	(+)
	Highly fertile or not	(+)
	Total value of insecticide used	(+)
	Total value of herbicide used	(+)
	Total value of fungicide used	(+)
	Tropical Livestock Unit	(+)
	Number of IDIR members in close relationship within the GOT	(+)
	Number of IQUB members in close relationship within the GOT	(+)

	Number of DEBBO participants in close relationship within the GOT	(+)
	Number of JIGGE participants in close relationship within the GOT	(+)
Exposure	Change in temperature	(-)
	Change in precipitation	(-)
Sensitivity	Type of shock -Drought	(-)
	Type of shock -Flood	(-)
	Type of shock -Hailstorm	(-)
	Population density	(-)

4.3. Data and Study Area Description

We use a survey of 1000 farm households conducted during the 2004/05 fiscal year in the Nile Basin of Ethiopia. The survey was conducted by the International Food Policy Research Institute (IFPRI) in collaboration with the Ethiopian Development Research Institute (EDRI). The sampled districts for the survey were selected to represent the different attributes of the basin, including typologies of the regions' agro-ecological zones, average annual rainfall, rainfall variability, and vulnerability (food aid-dependent population). Peasant associations (administrative units lower than districts) were also purposefully selected to include households that irrigate their farms. One peasant association was selected from each of 20 sampled districts, for a total of 20 sampled peasant associations. Once the peasant associations were chosen, 50 farming households were randomly selected from each peasant association (peasant associations have more than one village) for a total of 1000 interviewed households (Deressa 2008b). (See Table 2).

Data on precipitation and temperature for 2004/04 and 1994/05 was also obtained from the Ethiopian Metrological Agency (EMA). The analysis is based on four agro-ecological zones, namely moisture-reliable humid lowlands, moisture-sufficient highlands (cereal based), moisture sufficient highlands (*enset* based), and drought-prone highlands. In addition, district level results are also attached in the appendices.

Table 2. Surveyed Districts and Peasant Associations

Regional State	Zone	District	Agro-ecological zone	Peasant association	Number of households
Tigray	East Tigrai	Hawzein	Drought-prone highland	Selam	50
		Atsbi Wonberta	Drought-prone highland	Felge Woine	50
	South Tigrai	Endomehoni	Drought-prone highland	Mehan	50
Amhara	North Gondar	Debark	Humid lowlands	Mekara	50
		Chilga	Humid lowlands	Teber Sekro	50
		Wogera	Humid lowlands	Sak Debir	50
	South Gondar	Libo Kemkem	Humid lowlands	Angor	50
	East Gojam	Bichena	Humid lowlands	Aratband Bichena	50
	West Gojam	Quarit	Humid lowlands	Gebez	50
Oromiya	West Wellega	Gimbi	Humid lowlands	Were Sayo	50
		Haru	Humid lowlands	Genti Abo	50
	East Shoa	Bereh Aleltu	Cereal-based moisture sufficient highlands	Welgewo	50
	East Shoa	Hidabu Abote	Cereal-based moisture sufficient highlands	Sira marase	50
	East Wellega	Limu	Humid lowlands	Areb Gebya	50
		Nunu Kumba	Humid lowlands	Bachu	50
	Jimma	Kersa	Cereal-based moisture sufficient highlands	Merewa	50
Benishangul Gumuz	Metekel	Wonbera	Drought-prone highland	Addis Alem	50
	Asosa	Bambasi	Humid lowlands	Sonka	50
	Kamashi	Sirba Abay	Drought-prone highland	Koncho	50
SNNP	Zone 1	Gesha Daka	Enset-based moisture sufficient highlands	Kicho	50
Total					1000

The Nile Basin of Ethiopia is the area of focus in this study. The Nile Basin of Ethiopia covers a total area of about 358,889 km^2, which is equivalent to 34 percent of Ethiopia's total area, and contains about 40 percent of the country's population. Portions of six different regional states of Ethiopia are contained within the basin. Specifically, the basin encompasses 38 percent of the total land area of Amhara, 24 percent of Oromia, 15 percent of Benishangul-Gumuz, 11 percent of Tigrai, 7 percent of Gambella and 5 percent of Southern Nations Nationalities and Peoples (SNNP). The basin contains three major rivers: the Abbay River, which originates from the central highlands; the Tekeze River, which originates from the north-western part of the country; and the Baro-Akobo River, which originates from the south-western part of the country. The total annual surface runoff of the three rivers is estimated at 80.83 billion cubic meters per year, which amounts to nearly 74 percent of the total runoff from Ethiopia’s 12 river basins (Deressa 2007).

5. Results and Discussion

5.1 Descriptive Statistics

Our summary statistics in Table 3 show that not much difference is observed across agro-ecological zones in household variables such as gender, age, marital status and education. In all the zones, distance to the nearest water source is greater than 0.5 km, indicating that water supply is difficult to access in those regions of the country. The lowest use of training and extension services is observed in enset-based moisture-sufficient highlands. Humid lowland moisture-reliable areas show the highest frequency of extreme events such as drought, flood and hailstorms. On the other hand, enset-based moisture-sufficient highland areas did not experience any extreme climate events over the prior five years. Farmers living in enset-based moisture sufficient highland areas are wealthier than those in the other regions in terms of livestock (TLU). Similarly, those farmers have the highest social interaction of all the regions. Drought-prone highlanders used the least technology, i.e., insecticides, pesticides and fungicides. The highest incremental increase in temperature from 1994/95-2004/05 is found in drought-prone areas of the Nile Basin region. Of all the agro-ecological zones, the most densely populated area is the cereal-based-moisture sufficient highland.

Table 3. Summary Statistics (Mean) of Normalized Values of the Original Data by Their Respective Means and Standard Deviations by Agro-ecology

Description	AEZ1		AEZ2		AEZ3		AEZ4	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Gender of the hh head is male	0.912	0.283	0.840	0.368	1.000	0.000	0.892	0.312
Age of the hh head	44.370	13.681	47.767	15.142	43.340	12.103	44.759	13.468
Marital status of the hh head (married)	0.901	0.298	0.827	0.380	0.940	0.240	0.815	0.389
No. of years of education of the hh head	1.732	2.827	1.653	2.788	1.860	2.828	1.614	2.630
Primary residence with metal roof	0.589	0.493	0.308	0.463	0.061	0.242	0.333	0.472
Major source of domestic water	0.395	0.489	0.387	0.489	0.380	0.490	0.500	0.501
Distance of water source from home (domestic) in km	0.855	1.624	5.302	32.044	2.732	14.107	3.469	27.048
Have you attended training on crop production?	0.493	0.500	0.067	0.250	0.060	0.240	0.256	0.437
Have you attended training on livestock activities?	0.460	0.499	0.040	0.197	0.000	0.000	0.232	0.423
Do you get advice from extension workers on crop production?	0.691	0.463	0.140	0.348	0.080	0.274	0.544	0.499
Do you get advice from extension workers on livestock activities?	0.605	0.489	0.113	0.318	0.020	0.141	0.500	0.501
Distance of nearest market place for selling products (Hrs)	5.498	4.381	5.393	3.683	7.207	2.405	5.815	5.244
Distance of nearest market place for obtaining inputs (Hrs.)	5.615	4.088	5.526	3.724	7.467	2.468	5.632	4.587
Total area of farmland	2.174	1.676	2.240	1.360	2.923	3.817	1.742	1.363
Highly fertile or not	0.451	0.498	0.487	0.501	0.360	0.485	0.516	0.501
Total value of insecticide used	3.842	21.157	0.882	7.766	0.000	0.000	2.272	16.791
Total value of herbicide used	13.353	193.228	17.242	33.195	118.640	226.962	3.599	14.634
Total value of fungicide used	0.131	2.287	0.373	4.572	3.040	17.474	0.100	1.581
Tropical Livestock Units	4.516	3.036	5.379	3.873	6.859	3.515	4.512	3.401
Number of IDIR members in close relationship within the GOT	16.689	39.622	16.827	28.836	16.400	19.008	22.616	48.368
Number of IQUB members in close relationship within the GOT	0.575	2.859	0.687	4.055	3.660	11.705	2.512	6.812
Number of DEBBO participants in close relationship within the GOT	6.936	14.737	7.647	9.203	15.460	16.066	7.040	10.903
Number of JIGGE participants in close relationship within the GOT	1.224	5.147	2.640	6.029	0.220	1.418	0.760	1.969

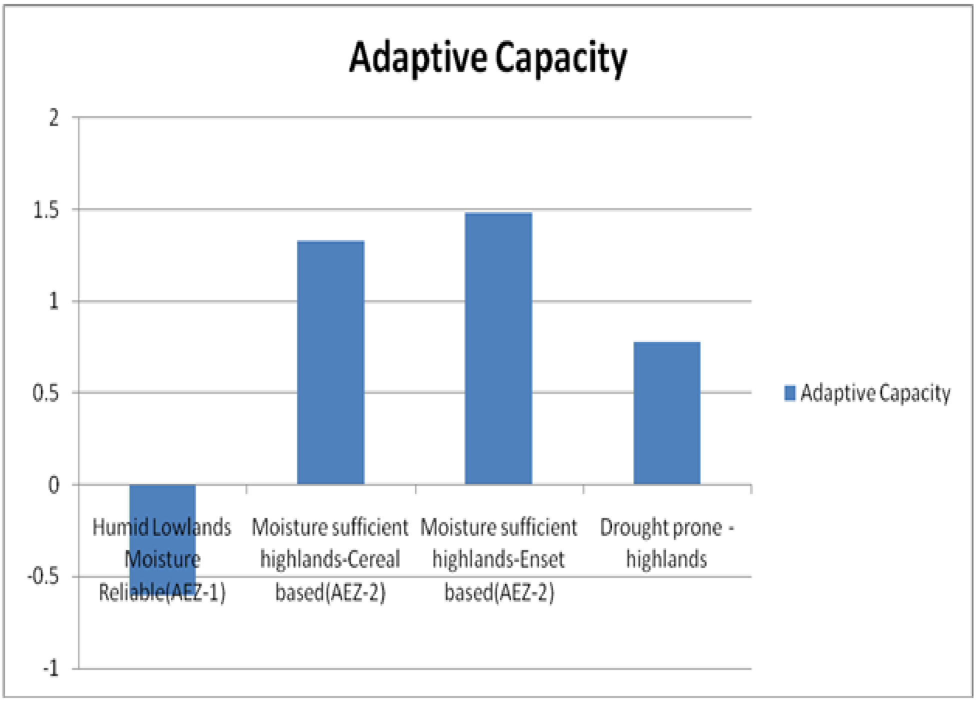
5.2 Empirical Results

In what follows, we first discuss the results in relation to each of the three dimensions of vulnerability and then turn to overall vulnerability.

Adaptive Capacity

Figure 2 presents the adaptive capacity index, which suggest large differences across agro-ecological zones of the Nile Basin of Ethiopia. Our findings also show that, among the four major agro-ecological zones in the basin, the enset based moisture sufficient highland areas have the highest adaptive capacity, with an index of 1.48. This is perhaps due to better access to infrastructure, asset accumulation and social networks. By contrast, the humid lowland zone is the lowest in terms of adaptive capacity to climate change, with the value of -0,6.

Figure 2. Adaptive Capacity across Agro-ecological Zones of the Nile Basin of Ethiopia

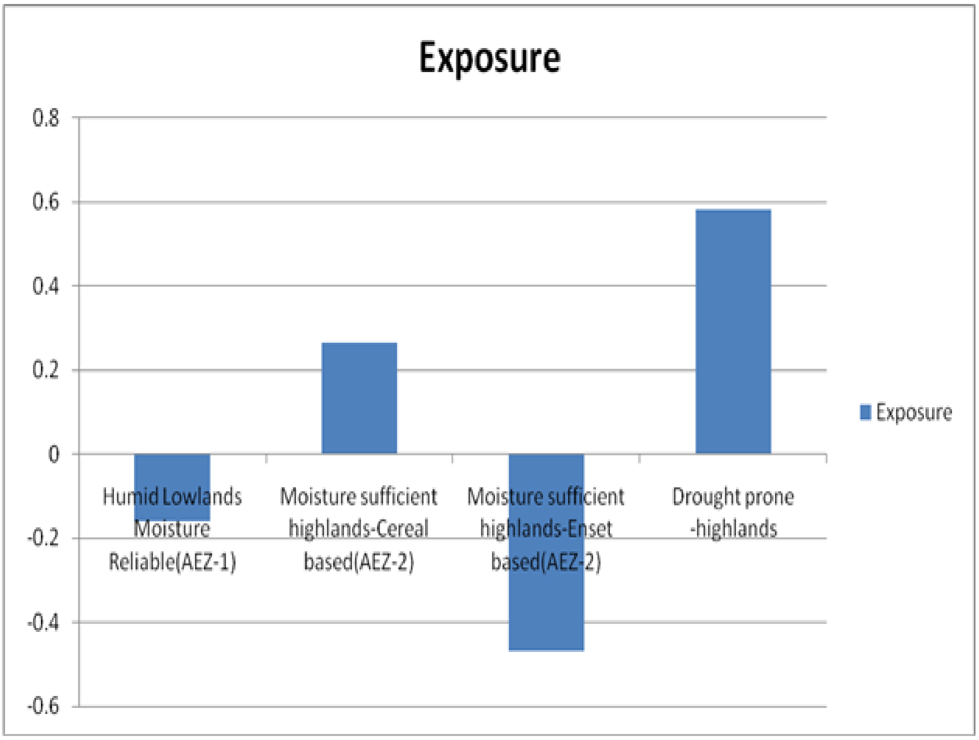


Exposure

The overall exposure of the farming sector across the four agro-ecological zones of the Nile Basin of Ethiopia is presented in Figure 3. Drought prone highland areas are the most exposed to climate change (0.6). The area is characterized by high temperature that is increasing over time. The least exposed agro-ecological zone is the enset-based moisture sufficient highlands (0.47), followed by moisture-reliable humid lowland areas

(-0.16), even though, in both zones, the amount of precipitation has been declining over time.

Figure 3. Exposure across Agro-ecological Zones of the Nile Basin of Ethiopia



Sensitivity

Regarding sensitivity, even though population density is highest in the moisture-sufficient highland areas, those areas tend to be the least sensitive zones in the study area (Figure 4). As in the exposure index, drought-prone highland areas are the most sensitive zone to climate change. The area is characterized by higher frequency of drought, flooding and hailstorms, in addition to high temperature that is increasing over time.

Figure 4. Sensitivity across Agro-ecological Zones of the Nile Basin of Ethiopia

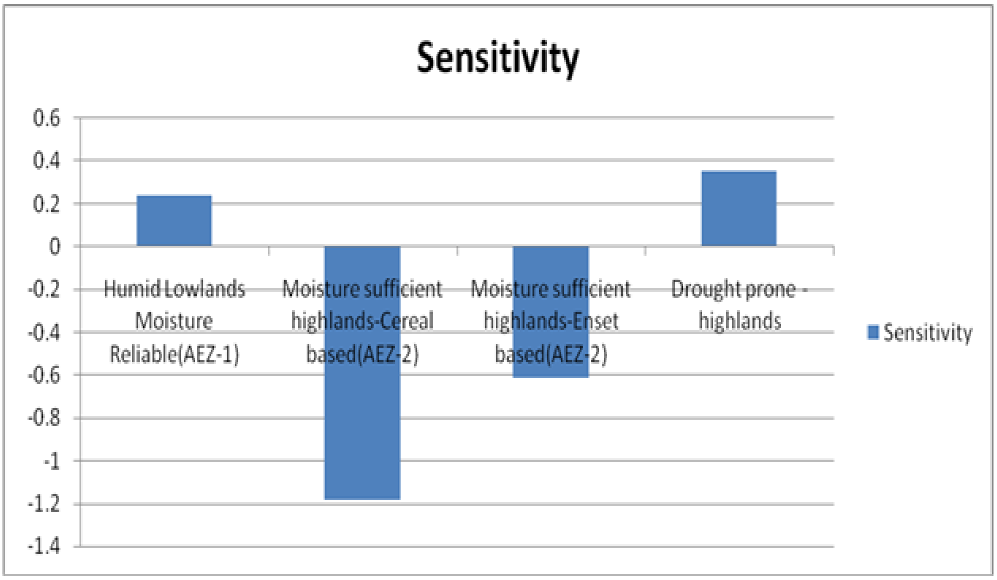
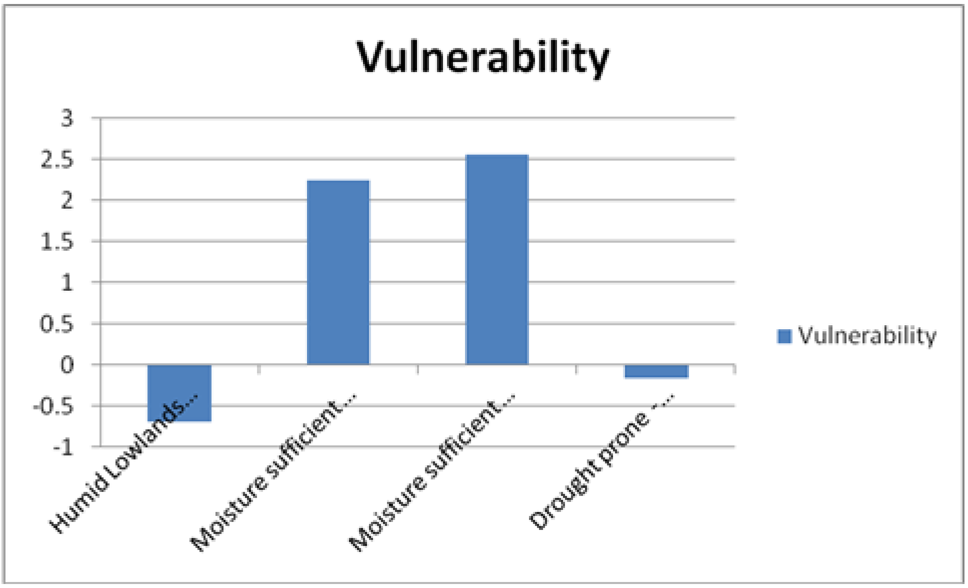


Figure 5. Overall Vulnerability across Agro-ecological Zones of the Nile Basin of Ethiopia



Overall Vulnerability

Following the results above, Figure 5 shows us potential impacts (exposure and sensitivity) and coping capacity (adaptive capacity) across different agro-ecological zones of the Nile Basin. The results of the overall vulnerability index also identified the humid lowlands (-0.68) and drought-prone highland areas (-0.16) of the Nile Basin of Ethiopia as the most vulnerable zones. This is because of their lower adaptive capacity and higher exposure and sensitivity to climate change. The less vulnerable zones are the enset-based moisture-sufficient highland zone (2.56) and cereal-based moisture-sufficient highland zone (2.25).The aggregated and disaggregated results of the overall vulnerability indices are consistent with the results at the district level, which are shown in the appendix.

6. Conclusions and Implications

The growing literature on climate change and agriculture has highlighted that the agricultural sector in poor countries in tropical and sub-tropical regions is vulnerable to climate change. Ethiopia is not an exception. Assessing vulnerability to climate change at various levels is essential for the planning and targeting of proactive and planned adaptations. Thus, the main objective of this paper is to analyze the vulnerability of Ethiopian farmers to climate change across different agro-ecological zones by constructing vulnerability indices and comparing the indices, taking the Nile Basin as a case study. Using the indicator method, we assess vulnerability by integrating indicators to form a composite index. We use IPCC's (2001) definition of vulnerability. Our vulnerability indicator approach is integrated, in that the selected indicators represent both the biophysical conditions of the farming regions and the socioeconomic conditions of the farm households.

We use a survey of 1000 farm households conducted during the 2004/05 fiscal year in the Nile Basin of Ethiopia. The survey was administered by the International Food Policy Research Institute (IFPRI) in collaboration with the Ethiopian Development Research Institute (EDRI). The analysis is based on four agro-ecological zones, namely moisture-reliable humid lowlands, moisture-sufficient highlands (cereal-based), moisture-sufficient highlands (enset-based), and drought-prone highlands. Vulnerability has three components: exposure, sensitivity and adaptive capacity. To quantitatively assess overall vulnerability and its components, we run a Principal Component Analysis (PCA) with 30 indicators, using data analysis and statistical software (STATA). PCA is used to generate weights for the different indicators, and overall vulnerability and its component indices are calculated.

Our findings show that, among the four main agro-ecological zones in the basin, enset-based moisture-sufficient highland areas have the highest adaptive capacity, perhaps due to better access to infrastructure, asset accumulation and social networks. By contrast, humid lowland zones are the lowest in terms of adaptive capacity to climate change. Regarding exposure and sensitivity, even though population density is highest in the moisture-sufficient highland areas and the precipitation amount is declining over time, those areas tend to be the least exposed and sensitive zones in the study area. Drought-prone highland areas are the most exposed and sensitive zones to climate change. The area is characterized by higher frequency of drought and flood, in addition to greater temperature increase through time. The results of the overall vulnerability index also identified the humid lowlands and drought-prone highland areas of the Nile Basin of the country as the most vulnerable zones. This is because of their lower adaptive capacity and higher exposure and sensitivity to climate change. The less vulnerable zones are the enset-based moisture-sufficient highland zone and the cereal-based moisture-sufficient highland zone.

Generally, our agro-ecological analysis provides useful insights and captures local specific variations that are often overlooked in earlier studies. The findings imply that climate change should be placed within the broader context of development strategy and rural poverty reduction. Because there are large spatial differences of vulnerability across agro-ecological zones, the development and rural poverty reduction policies and strategies should be tailored to location-specific circumstances. In particular, great effort should be exerted in expansion of education, training and extension to marginalized areas. Moreover, public investment in technology and infrastructure is essential to enhance adaptive capacity. Investment in different water, land and forest conservation programs should be implemented at both community and household levels, in order to lessen sensitivity and exposure to climate risk of rural households in the Nile Basin of Ethiopia.

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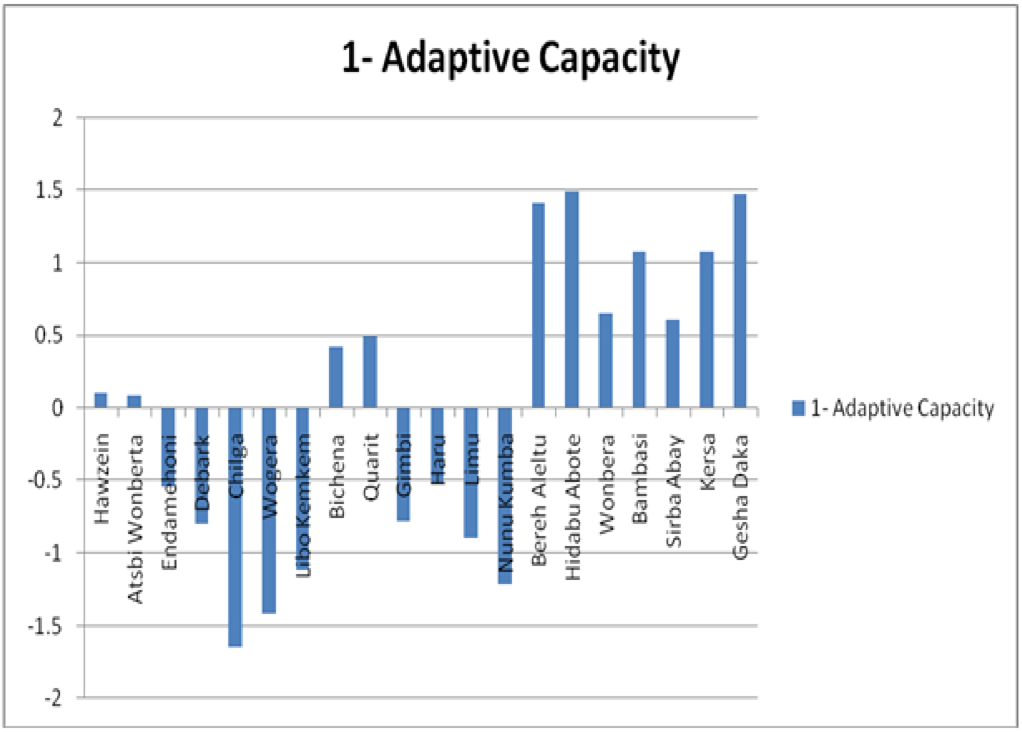
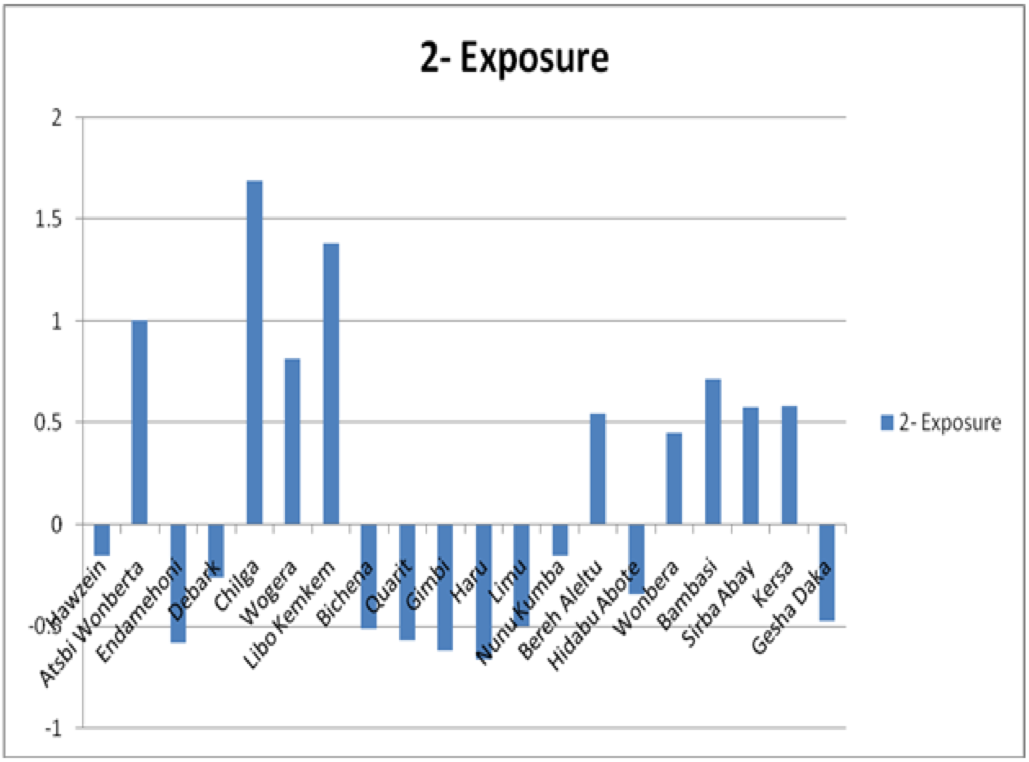
Appendix

Result of Vulnerability Indices across District Level of the Nile Basin of Ethiopia

1-Adaptive Capacity



2-Exposure


2- Exposure
2
1.5
1
0.5
0
-0.5
-1
Hawzein
Atsbi Wonberta
Endamehoni
Debark
Chilga
Wogera
Libo Kemkem
Bichena
Quarit
Gimbi
Haru
Limu
Nunu Kumba
Bereh Aleltu
Hidabu Abote
Wonbera
Bambasi
Sirba Abay
Kersa
Gesha Daka
2- Exposure

3-Sensitivity