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Assessment of the vulnerability of Ethiopian agriculture to climate change and farmers' adaptation strategies

By

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Dedication

To my late grandmother, Chewake Guteta Lemu

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Declaration

I declare that this thesis, which I submit for the degree of PhD in Environmental Economics at the University of Pretoria is entirely my own work and has not been submitted anywhere else for the award of a degree or otherwise.

Parts of the thesis have been published and submitted for publication in journals.

Any errors in thinking and omissions are entirely my own responsibility.

Signed..................................

Name: Temesgen Tadesse Deressa
July 2010

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Abstract

This study focused on two central themes. The first addressed the vulnerability of farmers to climate change at household and regional levels. The second theme analysed determinants of adaptation measures and factors influencing the perceptions of climate change in the Nile Basin of Ethiopia.

Three approaches are employed to address the above themes. The first approach is the vulnerability to expected poverty approach. It is based on estimating the probability that a given shock or set of shocks moves consumption by households below a given minimum level (such as a consumption poverty line) or forces the consumption level to stay below the given minimum requirement if it is already below this level. This is adopted to assess vulnerability at household level. Secondly, the method of principal component analysis (PCA) is employed to create vulnerability indices to conduct a comparative analysis of the vulnerability across regional states. Lastly, the Heckman selection probit model is used to analyse the two-step process of adaptation, which consists of perceiving a change in climate followed by taking appropriate adaptation measures in response.

Results indicate that vulnerability is highly sensitive to a minimum income requirement (poverty line) that farm households require to survive on a daily basis. For example, when the daily minimum income is fixed at US$0.3 per day, only 7 percent of farmers are vulnerable to future climate change, whereas at a minimum income level of US$2 per day, 93 percent of the farmers are vulnerable to climate extremes. Therefore, policies should encourage income generation and asset holding, both of which will enable consumption smoothing during and immediately after harsh climatic events. Results further show that the relatively least-developed, semi-arid and arid regions namely, Afar and Somali, are highly vulnerable to climate change. The large Oromia region, which is characterised both by areas of good agricultural production in the highlands and midlands and by recurrent droughts, especially in the lowlands, is also vulnerable. Furthermore, the Tigray region, which experiences recurring droughts, is also vulnerable to the negative impacts of climate change in comparison with the other regions. Integrated rural development policies, aimed at alleviating poverty with special emphasis on the relatively less-developed

regions of the country (i.e., Afar and Somali), can play a double role in reducing poverty and in increasing adaptive capacity to climate change.

The study also reveals that experienced farmers, more educated farmers, better-off farmers, better-informed farmers, farmers who access extension and credit services and those with stronger social networks are more likely to perceive climate change and adapt. Government policies and investment strategies that support the provision of and access to education; credit; extension services on crop and livestock production; information on climate and adaptation measures across different agro-ecologies and encourage informal social networks are necessary to better adapt to climate change in Ethiopia.

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Acronyms and abbreviations

ACCFP	African Climate Change Fellowship Program
ADLI	Agriculture Development Led Industrialization
AEZs	Agro-Ecological Zones
AFRODAD	African Forum and Network on Debt and Development
BC	Before Christ
BP	Biophysical
CEEPA	Centre for Environmental Economics and Policy in Africa
CGCM2	Coupled Global Climate Model Two
CGIAR	Consultative Group on International Agricultural Research
CPWF	Challenge Program on Water and Food
CSA	Central Statistics Authority
EC	Economic
EDRI	Ethiopian Development Research Institute
EM-DAT	Emergency Events Database
FC	Farm Characteristics
FFYP	First Five Year Plan
GDP	Gross Domestic Product
GOE	Government of Ethiopia
HaDCM3	Hadley Centre Coupled Model Three
HDI	Human Development Index
HHC	Household Characteristics
IFPRI	International Food Policy Research Institute
IMF	International Monetary Fund
INST	Institutional
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Inter-tropical Convergence Zone
MEDaC	Ministry of Economic Development and Cooperation
MMP	Minimum Package Program
MNL	Multinomial Logit

MoFD	Ministry of Finance and Development
MoFED	Ministry of Finance and Economic Development
MoWR	Ministry of Water Resources
NMS	National Meteorological Services
NMSA	Nationl Meteorological Services Agency
PA	Peasant administration
PADETES	Participatory Demonstration and Training Extension System
PCA	Principal Component Analysis
PCM	Parallel Climate Model
SFYP	Second Five Year Plan
SNNP	Southern Nations and Nationalities People
SRES	Special Report on Emissions Scenarios
START	System for Analysis, Research and Training
TFYP	Third Five Year Plan
UNDP	United Nations Development Programme
VEP	Vulnerability as Expected Poverty
VER	Vulnerability as Uninsured Exposure to Risk
VEU	Vulnerability as Low Expected Utility

CHAPTER 1

INTRODUCTION

1.1 Background and problem statement

Studies indicate that over the past years, mean temperature levels in Africa have increased whereas precipitation levels have declined (IPCC 2001). The temperature of the continent has also seen an increasing number of warm days and a decreasing number of extremely cold days (New *et al*. 2006). Spatial and temporal variability, more intense and widespread droughts and aggravated flooding have been experienced in Africa over the past few decades in addition to the decreasing trend in rainfall levels (Hulme *et a*l. 2001; Richard *et al*. 2001).

It is believed that Africa is highly vulnerable to climate change and climate variability due to the fact that the majority of the populations in Africa depend on subsistence rain-fed agriculture (Boko *et al.* 2007). Studies undertaken to analyse the impact of climate change on crop, livestock and mixed crop-livestock production in Africa indicated that the increasing temperature and a decrease in precipitation will significantly reduce income from agriculture (Kurukulasuriya and Mendelsohn 2008a; Hassan and Nhemachena 2008).

In Ethiopia, the average annual minimum temperature has increased by about 0.25^{o}C every ten years while the average annual maximum temperature has increased by about 0.1^{o}C. Additionally, the National Meteorological Services (NMS 2007) further showed that there was a very high variability of rainfall over the past 50 years. Even though there has also been a long history of droughts in Ethiopia, studies show that its frequency and spatial coverage have increased over the past few decades (Lautze *et al.* 2003). These trends of increasing temperature, decreasing precipitation and the increasing frequency of droughts and floods are predicted to continue in the future in the tropics of Africa where Ethiopia is located (World Bank 2003; Mitchell and Tanner 2006; IPCC 2001).

Agriculture contributes about 50% of the gross domestic product (GDP), generates more than 90% of the foreign exchange earnings and employs about 85% of the population in Ethiopia (MoFED 2008). This sector is dominated by small-scale mixed crop-livestock production with very low productivity. The major factors responsible for low productivity include: reliance on traditional farming techniques; soil degradation caused by overgrazing and deforestation; poor complementary services such as extension, credit, marketing and infrastructure; and climatic factors such as droughts and floods. These factors reduce the adaptive capacity or increase the vulnerability of farmers to future changes in climate and negatively affect the performance of the already weak agricultural production. This indicates that Ethiopia's agriculture must cope with further warming, low rainfall patterns and frequent climate extremes (such as droughts and floods) predicted for the future.

Studies have been undertaken to measure the impact of climate change on Ethiopian agriculture (Deressa 2007; NMSA 2001; Kidane *et al.* 2006) and water resources (Kinfe 1999; Lijalem *et al.* 2006; Deksyos and Abebe 2006). Studies on agriculture analysed monetary or yield impacts of climate change and suggested adaptation measures, but did not analyse factors affecting the choice of the suggested adaptation methods. This presents important limitations as a deep understanding of how farmers respond to climate change or their choice of adaptation methods, influenced by a host of socio-economic and environmental factors, is necessary for designing appropriate policy measures to enhance adaptation capacities of vulnerable farming populations.

Other studies have attempted to analyse the impact of climate change and influences of factors affecting the choice of adaptation methods in crop, livestock and mixed crop-livestock production systems (Kurukulasuriya and Mendelsohn 2008b; Seo and Mendelsohn 2008; Hassan and Nhemachena 2008), perceptions of and adaptation to climate change (Maddison 2006) in Africa at regional level. Results from these studies are highly aggregated and the parameters have limited value in identifying country-specific impacts and adaptation methods given the heterogeneity of countries studied. Additionally, these studies were based on data that did not take into account influences of social capital on farmers' adaptive capacities (Boko *et al.* 2007).

The primary objective of this study is therefore to analyse factors affecting the choice of adaptation methods and perceptions to climate change at country and local levels to bridge the gap of knowledge.

In addition to the gradual trends of increasing temperature and decreasing precipitation, which negatively affect agriculture, climate related risks (especially droughts and floods) are the other natural calamities impoverishing Ethiopian farmers. Dercon *et al.* (2005) indicated that adverse events that are costly to individuals in terms of lost income, reduced consumption and the sale or destruction of assets cause poverty. In Ethiopia, mainly droughts have been claiming lives at most and impoverishing households through the reduction in income and consumption at least mainly due to the dependence of the sector on rainfall and lack of insurance or social safety nets (Dercon 2004; World Bank 2003). In extreme cases, droughts in Ethiopia can shrink household farm production by up to 90 % of a normal year output (World Bank 2003).

Understanding vulnerability to risk of climate extremes is crucial for Ethiopia as it allows policy makers to devise a host of strategies and instruments towards risk management. Vulnerability to climatic risk can be defined from two perspectives: *ex ante* (‘before the event’) and *ex post* (‘after the fact’) approaches. The *ex ante* approach is based on measuring the probability of households’ consumption or utility falling below a given minimum level in the future due to current or past shocks, whereas the *ex post* methods measure welfare loss due to shocks (Hoddinott and Quisumbing 2003).

Attempts have been made to analyse the vulnerability of Ethiopian farmers to climatic and non-climatic shocks by using panel data sets (Dercon 2004; Dercon *et al.* 2005; Skoufias and Quisumbing 2003; Dercon and Krishnan 2000). The studies by Dercon (2004), Dercon *et al.*, (2005) and Dercon and Krishnan (2000) adopted the *ex ante* vulnerability assessment approach to analyse the vulnerability of Ethiopian farmers using a sample of only 15 villages. The Skoufias and Quisumbing (2003) study adopted the *ex post* approach to analyse vulnerability by using the same 15 villages used in the above described studies. While informative and methodologically sound, these studies are limited by their sample of 15 villages, which hardly represents the vast agro-ecology and socio-economic diversity of the country. This represents an important limitation since results from these studies cannot be generalised to farming communities living in and coping with different socio-economic and environmental circumstances. Regional states of the country are known to have different levels of vulnerability as they differ both in socio-economic and environmental attributes. The substantial variation in levels of vulnerability requires deeper knowledge of most vulnerable regions and what effective policy interventions are needed. MoFED (2008) studied the vulnerability of regional states of Ethiopia by comparing their coping capacity. The said study, however, is limited to only assessing the capacity of farmers to raise money to meet urgent (emergency short-term) needs induced by shocks and did not include a host of socio-economic and biophysical factors that define their vulnerability.

This study attempts to bridge the gaps of knowledge by using a cross section data set collected from 162 villages in the Nile Basin of Ethiopia with diverse socio-economic and environmental settings and secondary data collected on the various socio-economic and environmental attributes of the regional states of Ethiopia.

1.2 Objectives of the study

The primary objective of this study is to analyse the vulnerability of Ethiopian farmers to climate hazards and extreme events both at regional and household levels and to examine how farmers in Ethiopia have perceived and adapted to climate change.

The study intends/aims to pursue the following specific objectives under this main goal:

1. Identify households that are vulnerable to climate extremes such as droughts, hailstorms and floods and their specific characteristics in the Nile Basin of Ethiopia.

2. Identify the agro-ecology with the most vulnerable households in the Basin.

3. Identify the most vulnerable regional states of Ethiopia to climate change.

4. Analyse determinants of farmers' choice of adaptation measures in the face of climate change.

5. Analyse determinants of farmers' perception of climate change.

6. Identify policy options that would strengthen the adaptive capacity of farmers and reduce vulnerability to the negative impacts of expected future changes in climate.

1.3 Hypotheses of the study

The study plans to achieve the above stated objectives by performing formal tests of the following hypotheses:

1. Farmers in the Nile Basin of Ethiopia are vulnerable to the negative impacts of climate change.

2. The degree of vulnerability of farmers to climate change varies significantly across different household characteristics, agro-ecological settings and regional states.

3. Warmer temperatures and dryer climates are the strongest determinants of farmers' choices of adaptation methods.

4. Access to basic economic infrastructure, functioning social institutions, farm assets and technology are critical factors for enhancing farmers' adaptive capacity (reduced vulnerability) to climatic risks.

1.4 Approaches and methods of the study

This study adopts three approaches to investigate the vulnerability of Ethiopian agriculture and farmers' perception of and adaptation to climate change. Firstly, the probability of households falling below a given income level, due to climate extremes, is analysed using the *ex ante* measurement approach. Secondly, the method of principal component analysis (PCA) is employed to create vulnerability indices to conduct a comparative analysis of the vulnerability across regional states. Method three employs the Heckman selection probit model to analyse the two-step process of adaptation, which consists of perceiving a change in climate followed by taking appropriate adaptation measures in response. The study will collect information from household surveys and secondary sources to conduct the intended analysis. The Nile Basin of Ethiopia is selected as the case study due to the availability of data.

1.5 Organisation of the thesis

Chapter 2 provides an overview of the agricultural sector and climate in Ethiopia. Chapter 3 presents a review of literature on vulnerability and adaptation to climate change. Specifications of the household and regional vulnerability assessment models and results from the empirical analysis of these models are presented and discussed in Chapter 4. Chapter 5 describes the specifications of the Heckman selection probit model and discusses the results from the empirical analysis of this model. Summaries and Conclusions of the study are presented in Chapter 6.

CHAPTER 2

OVERVIEW OF THE AGRICULTURAL SECTOR AND CLIMATE IN ETHIOPIA

2.1 Introduction

Ethiopia has a total area of 1.1 million square kilometers. It is characterised by its high geographical diversities with altitudes ranging from 125 meters below sea level in the Danakil depression to 4620 meters above sea level in the peaks of Semien mountain ranges. The country has a total population of 79.3 million with a growth rate of 2.3 percent. Its economy is mainly based on rain-fed agriculture which is the source of livelihood for the majority of its population (CSA 2008).

Ethiopia is one of the poorest countries in the world with 38% of its population living under the poverty line (MoFED 2007). It has a human development index (HDI) of 0.406, ranking 169th out of 177 countries (UNDP, 2008). One of the major reasons for this high poverty in the country is the dependence of the economy on agriculture which had failed to meet the growing food demands of the population and left the nation dependent on food aid. Many factors contribute to the poor performance of the agricultural sector, including traditional farming practices, ineffective policy and poor climatic conditions, especially recurring droughts (Deressa 2007; Admassie and Adenew 2007).

These constraining factors increase the vulnerability of rural households to any external shocks such as climate change. Good knowledge of the potentials and constraints of the sector and the vulnerability of farmers and options to adapt to climate change will play a major role in coping with the negative impacts of climate change through effective policy formulation.

This chapter starts by describing the agricultural sector and summarising its performance. Section two gives an assessment of the past and current policy environment towards increasing productivity in the agricultural sector. Section three describes the agro-ecological features, past climate trends and future forecasts in Ethiopia. Section four describes the vulnerability of

Ethiopian farmers to climate change by assessing the linkages between the country's climate and agriculture. Section five presents summaries of the chapter.

2.2 Performance of the agricultural sector

Out of the total area of Ethiopia, about 73.6 million hectares (66 %) is potentially suitable for agricultural production out of which only 16.5 million hectares (22 %) is cultivated. The majority of the cultivated land (about 96%) is managed by mixed crop-livestock farmers, who own less than two hectares per household, including grazing land (MoFED 2007). Farming is practiced under five major farming systems namely: the highland mixed farming system; the lowland mixed agriculture; the pastoral system; shifting cultivation; and commercial agriculture (Befekadu and Berhanu 2000). The highland areas, which constitute about 95 percent of the cultivated land, are home to more than 90 percent of the Ethiopian population and 75 percent of livestock population.

Agriculture remains by far the most important sector in the Ethiopian economy for the following reasons: (i) it directly supports about 85% of the population in terms of employment and livelihood; (ii) it contributes about 50% to the country's gross domestic product (GDP); (iii) it generates about 90% of export earnings; and (iv) it supplies around 70% of the raw material requirements of agro-based domestic industries (MoFED 2008). It is also the major source of food for the population and hence the prime contributing sector to food security. In addition, agriculture plays a key role in generating surplus capital to speed up the country's overall socio-economic development (MoFED 2008).

Despite its high contribution to the economy, its performance has been very poor over the past few years. For instance, when the population grew by 2.9 percent per year between 1980 and 1990, value added in the agricultural sector and allied activates in 1980 constant factor cost grew by about 1.3 percent (Figure 1). The low performance in the agricultural sector was partly attributed to the ineffective policies of the then socialist-oriented military government. After the downfall of the socialist regime, the new government focused on the Agricultural Development Led Industrialization policy (ADLI) to increase productivity in the agricultural sector and sustain the economy. Partly due to the new economic policy and favourable climatic conditions, the productivity of agriculture and other macroeconomic indicators of the country have improved since 1992 (Figure 1). For instance, during the 2007 production year, Ethiopia recorded a total GDP growth rate of 11.4 percent, whereas value added in the agricultural sector grew by 9.4 percent in 1990 constant prices. The growth in the agricultural sector has been attributed to both increments in areas under cultivation and improvements in productivity. Between 1995 and 2007, there has been an increasing trend of both areas under cultivation and productivity .The annual growth rates for areas under cultivation and productivity have almost equally increased by 2.94 and 2.93 percent, respectively (Table 1).

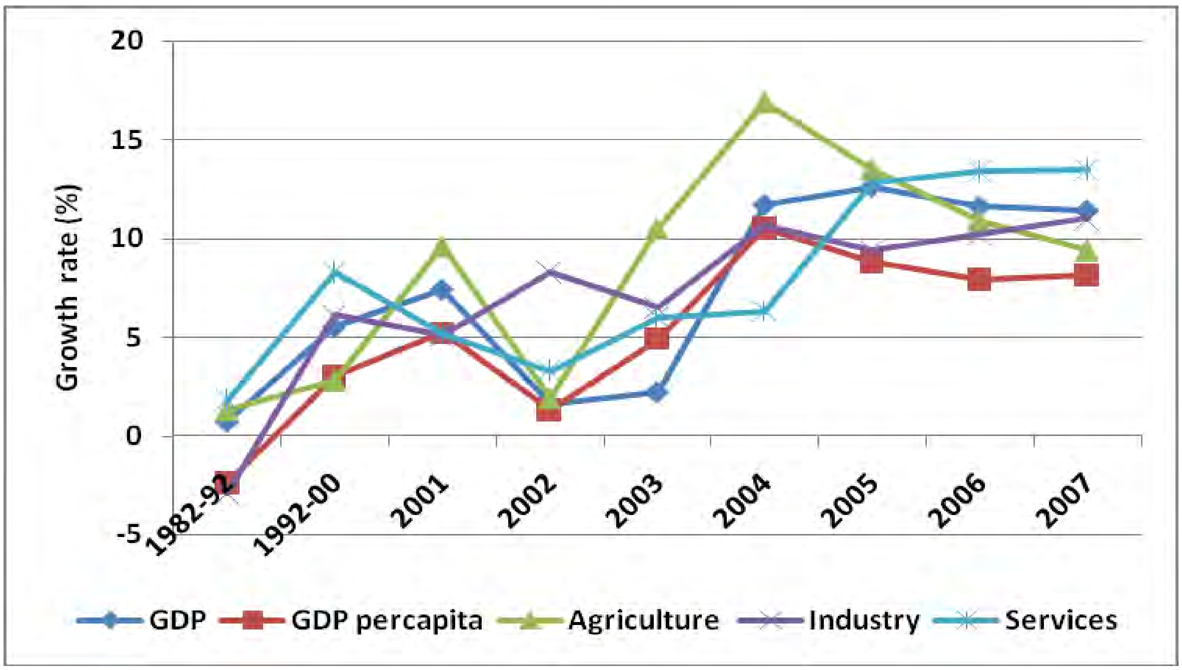

Figure 1**:** Annual growth rate of key economic indicators in Ethiopia (1982-2007)
(World Bank 2004; MoFED 2008)

Despite reported growth both in the overall economy and the agricultural sector, Ethiopia remained poor and dependent on foreign food aid. The total number of population needing food aid ranged from four million during years of good rainfall to 14 million during years of poor rainfall (Getachew 2005; GOE 2006).

Table 1: Trends in total production, area under production and productivity in Ethiopia (1995-2007)

Year	Total Production '000tons	Area cultivated '000ha	Productivity (tons per hectare)
1995	7889.51	7689.58	1.03
1996	11857.80	9037.96	1.31
1997	10605.10	8822.88	1.20
1999	10529.18	8811.03	1.19
2000	11067.57	9131.27	1.21
2001	12848.11	10437.13	1.23
2002	12168.41	8697.93	1.40
2003	8024.09	7866.76	1.02
2004	12810.69	9653.87	1.33
2005	11912.70	9817.00	1.21
2006	13381.80	10170.00	1.32
2007	14940.40	10576.00	1.41

Source: CSA (1997, 2001, 2005, 2008).

The big gap between the demand and supply of food is mainly attributed to the low performance of the agricultural sector despite efforts to increase productivity and food self sufficiency due to different socio-economic and environmental factors.

The major socio-economic constraints to improved crop production include: inappropriate polices; a decline in farm sizes and subsistence farming due to population growth; land degradation due to poor land management (cultivation of steep slopes, over cultivation and overgrazing); tenure insecurity; weak agricultural research and extension services; lack of agricultural marketing; inadequate transport networks; inadequate use of agricultural inputs; and the use of backward technologies.

The major causes of poor production in the livestock sub-sector include: inadequate feed and nutrition; low levels of veterinary care; high disease incidences; poor genetic structures; and limited infrastructure and research on livestock. The major environmental problem in both crop and livestock systems is recurring droughts, hailstorms, floods and pest incidences (Befekadu and Berhanu 2000).

In general, constraints to growth in the agricultural sector are associated with poverty where there is not enough investment in institutions, infrastructure and agricultural technologies, which make farmers vulnerable to environmental shocks such as droughts. The following section reviews the past and present agricultural policy environments, which are often cited as the prime causes of low agricultural productivity (Fasil and Habtemariam 2006; Demeke *et al.*1997, Adugna and Demeke, 2000).

2.3 The agricultural policy environment

Policy intervention to induce economic development in Ethiopia started during the Imperial regime focusing on the industrialisation of the economy under three policy phases. These were: the First Five Year Plan (FFYP) from 1957-1961; the Second Five year Plan (SFYP) from 1963-1967; and the Third Five Year Plan (TFYP) from 1968-1973.

The FFYP focused on the development of non-agricultural sectors. It considered crop production and cattle breeding by smallholder farmers as low-productive and traditional forms of economic activities. Two strategies were employed to increase agricultural production during this period. The first one was expanding land used for commercial agriculture and the second was increasing productivity through technology intervention (intensification), especially among smallholder farmers. To intensify the productivity of smallholder farmers, better farming implements such as iron-ploughs, harrows and improved sickles as well as improved seeds were distributed through the development of extension services. Despite these efforts, productivity of smallholder farmers and their level of integration in the economy did not improve (MoFD 1957).

The SFYP identified two major constraints to low productivity of smallholder farmers, which account for the majority of the Ethiopian population. The constraints were the feudal land tenure system and the failure of the FFYP to give enough attention to the agricultural sector. Thus, policy makers allocated more than 50% of the total public investment to the development of commercial farming to bring about growth in the agricultural sector (MoFD 1962). This enhanced the rapid expansion of commercial farming. The expansion of commercial farms resulted in the eviction of tenants and nomads. The eviction of peasants and nomads from productive land led to their settlement in drier and less productive areas, thus increasing unemployment, poverty and social unrest (Mengisteab 1989).

The TFYP acknowledged the inherent structural problems associated with the feudal system and recognised the need to give more attention to increase the productivity of smallholder farmers. To increase productivity, TFYP came up with a strategy of modernising smallholder agriculture through the allocation of financial and human resources to high potential areas which were called Minimum Package Programs (MPP). The minimum package program consisted of high yielding varieties, fertilizers, pesticides, irrigation and extension services (MoFD 1967). Despite promising initiatives, the minimum package program was not effective in changing smallholder agriculture. Major reasons for the failure include: the high cost of technology and extension system in terms of finance and manpower; poor coordination among stakeholders; and the structural problems associated with the feudal land tenure system (Tennasie, 1985).

The structural problems of the feudal system were associated with the landlord-tenant relationship that forces peasants to give a major share of their production to landlords. The landlords had either ownership or usufruct rights over land and used to lease out land to tenants on a sharecropping basis. The high rates of sharecropping prevented capital formation and productivity raising investments by farmers (Mengisteab 1989). Moreover, the feudal tenure system discouraged the adoption of new technologies making it unprofitable to peasants as benefits from adopting new technologies went to landlords (Tecle 1975: Cited by Mengisteab 1989).

To solve the structural problem with the feudal system, TFYP included a draft proclamation that was presented to the parliament requiring a policy shift in landlord-tenant relationships in favour of peasants. The draft document was rejected by the majority of the members of parliament who used to have huge tracts of land and felt threatened by these modest adjustments in the system (Getachew 2005). The failure of the imperial regime to accept the request for land reform, the associated social unrests, the failed agriculture of the peasants and the drought in 1973 and 1974, which led to famine that claimed millions of lives, finally led to the downfall of the Imperial regime.

The military regime which took over power from the Imperial regime relaxed the structural problems associated with the feudal land tenure system by redistributing land to smallholder farmers. This regime started an intervention to increase smallholder productivity by further extending the earlier initiatives of the MPP to more areas, but maintained the focus on industrialisation as the main driver of economic development. Attempts to increase productivity of smallholder farmers did not achieve satisfactory results mainly due to the gap between extension agents, who were concentrated in a district level, and the vast majority of farmers scattered over remote wide areas (Getachew 2005). In response to this, the then government focused on the reorganisation of smallholder farmers into producers and service cooperatives to promote mechanisation. Agricultural pricing and marketing policies were also introduced particularly to control input and output prices in addition to the promotion of large scale state farms which were meant to meet domestic consumption demands and promote exports. Instead of increasing productivity, the formation of farmers' cooperatives, peasant associations and implementation of agricultural pricing and marketing polices served as instruments of surplus extraction, state control and regimentation (Getachew 2005). Thus, replacing the feudal system with cooperatives did not provide the effective incentive system to increase productivity as both systems do not provide tenure security.

The then government attributed the failure of smallholder agriculture to: technological backwardness; scattered farmlands; massive deforestation; and soil erosion. It was believed that countrywide resettlement and villagisation schemes alongside the formation of famers' cooperatives with better extension programmes could solve the problem of low productivity of smallholder farmers (Getachew 2005). Attempts to collectivise farmers to promote: mechanisation; large state farms; agricultural and pricing policies; and resettlement schemes, could not meet the goal of increasing food productivity and attaining food self-sufficiency. Growth of the economy in general and that of agriculture was disappointing due to: unfavourable agricultural policies; recurring droughts; and civil war which led to the downfall of the regime.

The current government of Ethiopia switched from the socialist economy of the past regime to a more liberal and market-based economy. Through financial support from the International Monetary Fund (IMF) and its structural adjustment programmes, Ethiopia underwent many policy changes. Major policy changes that were implemented include the: devaluation of the local currency; disbanding of producer cooperatives; elimination of compulsory grain quotas; and liberalisation of input and output markets (MEDaC 1999; Gelan, 2002; AFRODAD, 2005). Moreover, the government changed the philosophy of industrialisation-led economic development of the past regimes to agriculture-led economic development. To this effect, the government made key policy interventions that are meant to promote the agricultural sector by allocating major portions of the budget and manpower of the country to rehabilitate and develop small scale agriculture (Yirga 2007).

Agriculture Development Led Industrialization (ADLI) was adopted in 1995, to bring about growth in the agricultural sector to ensure food self-sufficiency and induce growth in the rest of the economy. A smallholder intensification extension programme called the Participatory Demonstration and Training Extension System (PADETES) was developed as an instrument for achieving the objectives of ADLI (Fasil and Habtemariam 2006). The primary focus of PADETES was on increasing the production and productivity of small scale farmers through better access to improved production technologies such as improved seeds, fertilizer and pesticides by emphasizing active participation of rural communities and other stakeholders (Fasil and Habtemariam 2006).

Following the implementation of PADETES over a wide area of the country, productivity increments were recorded indicating that success in increasing productivity of small scale farmers is potentially possible (Samuel 2006). Despite the promising potential revealed through the implementation of PADETES, a sustainable success story in the agricultural sector of the country is still yet to be celebrated due to a multitude of factors. Limitations are believed to include: lack of technological options suited for different agro-ecologies and different enterprises; limited capacity of institutions; poor credit systems; managerial and marketing problems; tenure insecurities; population pressure; and climatic conditions especially droughts (Mulat 2001; Tadesse 2002; Getachew 2005).

2.4 Climate in Ethiopia

2.4.1 Climate systems in Ethiopia

The Ethiopian climate is mainly controlled by the seasonal migration of the Inter-tropical Convergence Zone (ITCZ), which follows the position of the sun relative to the earth and the associated atmospheric circulation, in conjunction with the complex topography of the country (NMSA 2001). There are different ways of classifying the climatic systems of Ethiopia, including: the traditional; the Köppen's; the Thornthwaite's; the rainfall regimes; and the agro-ecological zone classification systems (Yohannes 2003).

The most commonly used classification systems are the traditional and the agro-ecological zones (AEZs). According to the traditional classification system, which mainly relies on altitude and temperature, Ethiopia has five climatic zones (Table 2).

Table 2: Traditional climatic zones and their physical characteristics (MoA 2000).

Zone	**Altitude (meters)**	**Average annual temperature (^oC)**
Wurch (upper highlands)	3200 plus	>11.50
Dega (highlands)	2,300 – 3,200	11.50 - 17.50
Weynadega (midlands)	1,500 – 2,300	16.00 - 20.30
Kola (lowlands)	500 – 1,500	20.00 - 27.50
Berha (desert)	Under 500	>27.50

The AEZs classification method alternatively is based on combining growing periods with temperature and moisture regimes. According to the AEZs classification system, Ethiopia has 18 major AEZs, which are further subdivided into 49 AEZs (Figure 2). These AEZs are also grouped under six major categories (MoA 2000), which include the following:

• Arid zone :	Arid zone: This zone is less productive and pastoral, occupying 53.5 million hectares (31.5 percent of the country).
• Semi-arid :	Semi-arid: This area is less harsh and occupies 4 million hectares (3.5 percent of the country).
• Sub-moist :	Sub-moist: This zone occupies 22.2 million hectares (19.7 percent of the country), highly threatened by erosion.
• Moist :	Moist: This agro-ecology covers 28 million hectares (25 percent of the country) of the most important agricultural land of the country where cereals are the dominant crops.
• Sub-humid and humid :	Sub-humid and humid: These zones cover 17.5 million hectares (15.5 percent of the country) and 4.4 million hectares (4 percent of the country), respectively. They provide the most stable and ideal conditions for annual and perennial crops and are home to the remaining forest and wildlife, having the most biological diversity.
• Per-humid :	Per-humid: This zone covers about 1 million hectares (close to 1 percent of the country) and is suited for perennial crops and forests.

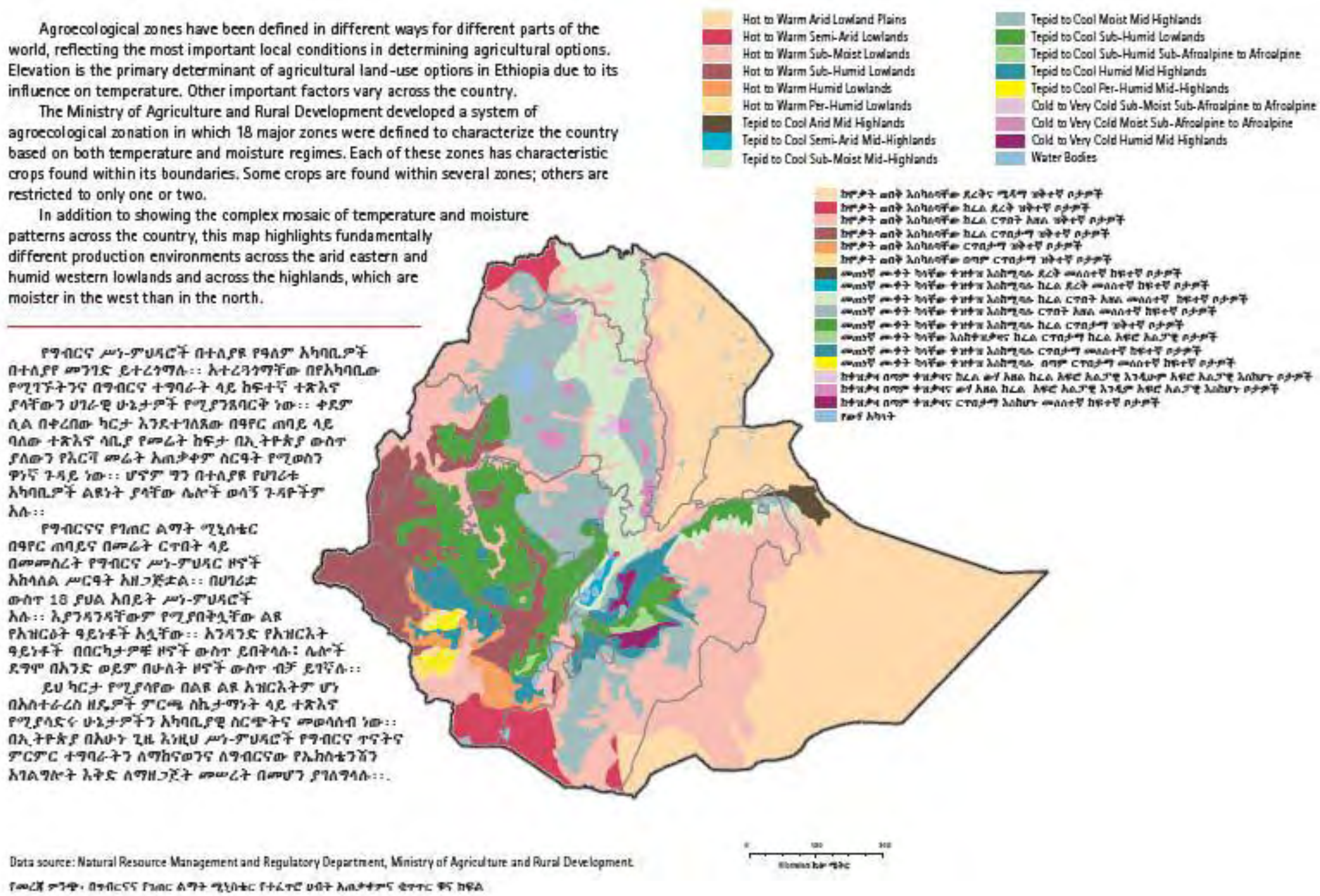

Figure 2: Agro-ecological zones of Ethiopia
(IFPRI 2006; CSA 2006; EDRI 2006)

Over these diverse AEZs, mean annual rainfall and temperature vary widely. Mean annual rainfall ranges from about 2,000 millimeters over some pocket areas in the southwest to less than 250 millimeters over the Afar lowlands in the northeast and Ogaden in the southeast. Mean annual temperature varies from about 10^0C over the high table lands of the northwest, central and southeast to about 35^0C on the northeastern edges.

2.4.2 Past trends of climate in Ethiopia

In addition to variations in different parts of the country, the Ethiopian climate is also characterised by a history of climate extremes, such as: droughts and floods; and increasing and decreasing trends in temperature and precipitation, respectively. The history of climate extremes, especially drought, is not a new phenomenon in Ethiopia. Recorded history of droughts in Ethiopia dates back to 250 BC. Since then, droughts have occurred in different parts of the country at different times (Webb and von Braun 1994). Even though there is a long history of droughts in Ethiopia, studies show that the frequency of droughts has increased over the past few decades, especially in the lowlands (Lautze *et al.* 2003; NMS 2007).

Studies also indicate that mean temperature and precipitation have changed over time. According to NMSA (2001), the average annual minimum temperature over the country has increased by about 0.25^oC every 10 years, while the average annual maximum temperature has increased by about 0.1^oC every decade. The average annual rainfall of the country showed a very high level of variability over the past years, even though the trend remained more or less constant (NMS 2007). Over the past 60 years, some of the years have been characterised by dry rainfall conditions resulting in droughts and famine whereas the others are characterised by wet conditions (Figure 3). Droughts in Ethiopia can shrink household farm production by up to 90% of a normal year output (World Bank 2003). Most often, many farmers die of hunger or depend on foreign food aid during extreme drought periods. For instance, during the 1983/84 drought periods, about one million people died due to drought that led to famine. Many households have also been affected during drought periods over different years in the same vein (Table 3).

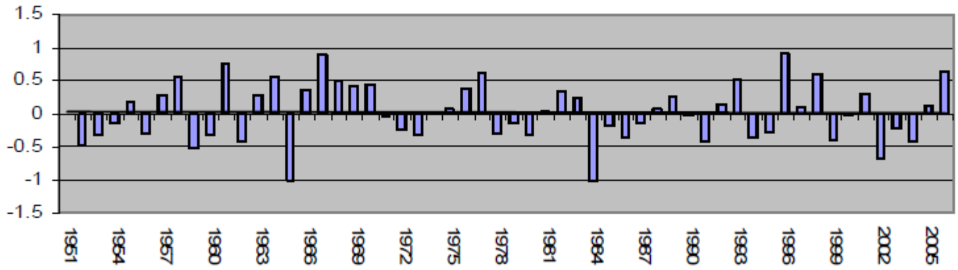

Figure 3: Year to year variability of annual rainfall and trends over Ethiopia expressed in normalised deviation (compared to 1971-2000 normal)
(NMS 2007)

The trends of the contribution of agriculture to total GDP of the country clearly explain the relationship between the performance of agriculture, climate and the total economy. As can be seen in Figure 4, years of drought and famine (1984/1985, 1994/1995, 1998/1999) are associated with very low contributions, whereas years with good climatic conditions (1982/83, 1986/1987, 1996/1997) are associated with better contributions.

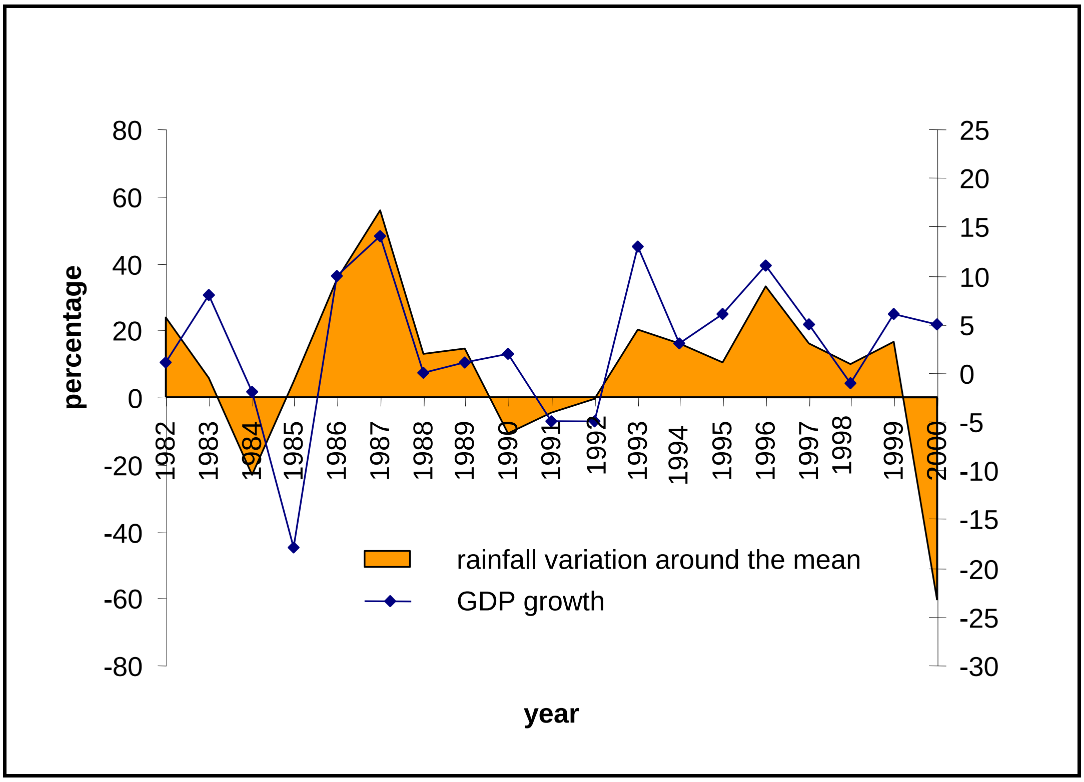

Figure 4: Rainfall variation and GDP growth
(World Bank 2006)

Table 3: Chronology of the Effect of Drought/Famine in Ethiopia (1965-2009)

Years	Regions Affected	Effects
1964-1966	Tigray and Wello	About 1.5 million people affected
1972-1973	Tigray and Wello	About 200,000 people and 30 percent of livestock died
1978-1979	Southern Ethiopia	1.4 million people affected
1983-1984	All regions	8 million people affected, one million people died
1987-1988	All regions	7 million people affected
1992	North, eastern and southern regions	About 500,000 people affected
1993-1994	Tigray and Wello	7.6 million people affected
2000	All regions	About 10.5 million people affected
2002/2003	All regions	About 13 million people affected
2008/2009	All regions	About 5 million people affected

Sources: Quinn and Neal (1987); Degefu (1987,); Nicholls (1993); Webb and Braun 1994; Government of Ethiopia (2009).

2.4.3 Projected climate in Ethiopia

Although models predicting precipitation give controversial results of both increasing and decreasing precipitation, all models agree that the temperature in Ethiopia will increase in the coming years. For instance, Strzepek and McCluskey (2006) showed that, based on different models, precipitation will either increase or decrease. They point out, however, that the temperature will increase under all models (Table 4).

Strzepek and McCluskey (2006) used three climate prediction models based on two scenarios from the IPCC Special Report on Emission Scenarios (SRES). These models are: the Coupled Global Climate Model (CGCM2) (Flato and Boer 2001): the Hadley Centre Coupled Model (HadCM3) (Senior and Mitchell 2000): and the Parallel Climate Model (PCM) (Washington *et al.* 2000). The two SRES scenarios used in the study are the A2 and B2 scenarios. The A2 scenario describes a world in which population growth, per capita economic growth and technological changes are heterogeneous across regions. The B2 scenario describes a world in which the population increases continuously across the globe at a rate less than A2. This scenario is an intermediate level of economic development that is oriented towards environmental protection and social equity with a focus on local and regional levels (IPCC 2001). Additionally, forecasts by NMS (2007) indicate that the temperature in Ethiopia will increase in the range of 1.7 – 2.1^{o} C by the year 2050 and 2.7 – 3.4^{o}C by the year 2080.

Table 4: Climate predictions for 2050 and 2100 (Changes from a 1961- 1990 base for SRES A2 and B2)

Model	**Temperature in ^{o} C**		**Precipitation change in %**	
	2050	**2100**	**2050**	**2100**
CGCM2				
A2	3.30	8.00	-13.00	-28.00
B2	2.90	5.10	-13.00	-28.00
HadCM3				
A2	3.80	9.40	9.00	22.00
B2	3.80	6.70	9.00	22.00
PCM				
A2	2.30	5.50	5.00	12.00
B2	2.30	4.00	5.00	12.00

Source: Strzepek and McClusky (2006).

2.5 Vulnerability of Ethiopian agriculture to climate change

The vulnerability of Ethiopian farmers to climate change is attributed to their dependence on rain-fed agriculture and high poverty. Rain-fed agriculture, which supports the livelihoods of the majority of the population, is highly sensitive to climatic conditions. It is characterised by: highly erratic rainfall; frequent droughts that often cause famines; and intensive rainfall that often cause floods. Given the dependence of the economy on agriculture and the dependence of the agricultural sector on climatic conditions, especially rainfall, the macroeconomic performance of the country follows rainfall patterns. As indicated earlier (in section 2.4.2), in years where there is good rainfall, the economy performs well and in years of bad rainfall the economy performs very badly.

Low levels of economic development or poverty is the other source of vulnerability of Ethiopian farmers. The majority of Ethiopian farmers have limited capacities to mitigate, adapt or cope with effects of climate extreme events such as droughts, which significantly reduce the already low consumption. In addition to creating severe food shortages, experiencing a drought at least once in five years lowers per capita consumption by about 20 percent (Dercon *et al*. 2005). Moreover, Dercon (2004) indicated that rainfall shocks have a substantial impact on consumption growth which persists for many years.

Both household and public level climate risk management through mitigation and coping practices are undertaken to reduce the damages from climate change. Risk mitigation strategies at household levels include: crop diversification; mixed crops and livestock production; keeping multiple species of livestock; and joining rotating credit groups. Coping strategies at household level include: selling productive assets; selling of livestock and agricultural products; reducing current investment and consumption; child labour; temporary or permanent migration; mortgaging of land; and use of inter-household transfers and loans. A country level study conducted by MoFED (2007) on the ability of farmers to cope with shocks revealed that the main coping strategies include: sellings of animals (40%); loans from relatives (18%); selling of crop outputs (14%); and own cash (9%).

Public level risk mitigation strategies include: water harvesting; resources conservation and management; irrigation; voluntary resettlement programs; household extension packages; agro-ecological packages; productive safety net programs; and the newly pilot studies (namely weather-indexed drought insurance and commodity exchange programs). Coping strategies include: free food distribution (mainly from food aid); and food for work programmes (MoFED 2008; Devereux and Guenther 2007). Food aid has become one of the most important coping strategies to fight drought and famine. For instance, Ethiopia required about 896,963 metric tons of food aid during the 2000/2001 drought period and needed about 455 million dollar worth of food aid during the 2008/2009 draught period (GOE 2009).

Even though they are very important for reducing vulnerability, both the household and public level risk mitigations as coping strategies have not proven to be wholly effective. Household risk management strategies are ineffective mainly due to the fact that: they achieve partial insurance at a very high cost; they are localised; they are limited in scope; and informal insurances marginalise the most vulnerable and have very high hidden costs (World Bank 2003). The limitations of public risk management strategies include: limitations of coverage; weak institutional linkages among stakeholders dealing with risk management;

poor early warning mechanisms; and the dependence on foreign source for food aid (World Bank 2003; Devereux and Guenther 2007).

2.6 Summary

This chapter described how important the agricultural sector is for the Ethiopian economy. The performance of agriculture has also been assessed as being poor over the past few years, despite different policy interventions under different political regimes. Poor performance of the sector has been attributed to different socio-economic and environmental factors. Major socio-economic constraints include: poor infrastructural and socio-economic setups; ineffective policies; population pressure; soil degradation; and low productive technologies. Whereas the major environmental constraints include: droughts; floods; hailstorms; and pest incidences.

According to the traditional classification system, Ethiopia has five climatic zones. These are: *Wurch* (Upper highlands), *Dega* (Highlands), *Weynadega* (midlands), *Kola* (lowlands) and *Bereha* (Dessert). Over these diverse agro-ecological settings, different types of crops and livestock species are produced as a means of livelihood for millions of smallholder farmers. The past trends in precipitation showed a very high level of variation, whereas the trends in temperature indicate a steady rise. Additionally, future forecasts indicate that the temperature will increase whereas precipitation will decrease (even though model results from some models indicate increasing precipitation).

Vulnerability of Ethiopian farmers to climate change is attributed to dependence on rainfall and poverty. The performance of the major macroeconomic indicators of the country move with the direction of rainfall; good rainfall means good economic performance and vice versa. Vulnerability due to poverty is attributed to the lack of effective, adaptive, coping and mitigation strategies, both at household and public levels.

CHAPTER 3

REVIEW OF LITRATURE ON VULNERABILITY AND ADAPTATION TO CLIMATE CHANGE

3.1 Introduction

Vulnerability is a widely used concept by different fields of specialisation and thus with different definitions (Füssel 2007). The concepts and definitions of vulnerability used by different scholars revolve around the explanation of lack of adaptive capacity in both social and natural systems. The knowledge of vulnerability of different social systems and the adaptation measures taken assist policy in vulnerability reduction through strengthening adaptive capacity. This chapter starts by giving a review of literature on concepts of vulnerability and the methods employed to analyse vulnerability to climate change. Section two describes the concept and definition of adaptation and the approaches to assessing adaptation to climate change. Section three summarises the chapter.

3.2 Concepts and methods to vulnerability analysis

There are three major conceptual approaches to analysing vulnerability to climate change: the socio-economic; the biophysical (impact assessment); and the integrated assessment approaches.

3.2.1 Socio-economic approach

The socio-economic vulnerability assessment approach mainly focuses on the socio-economic and political status of individuals or social groups (Adger 1999; Füssel 2007). Individuals in a community often vary in terms of: education; gender; wealth; health status; access to credit; access to information and technology; formal and informal (social) capital; political power; and so on. These variations are responsible for the variations in vulnerability levels. In this case, vulnerability is considered to be a ‘starting point’ or a ‘state’ (i.e. a variable describing the internal state of a system) that exists within a system before it encounters a hazardous event (Allen 2003; Adger and Kelly 2000). Thus, vulnerability is considered to be constructed by society as a result of institutional and economic changes (Adger and Kelly 1999). In general, the socio-economic approach focuses on identifying the adaptive capacity of individuals or communities based on their internal characteristics. A study by Adger and Kelly (1999) is an example of this approach. In their study, the environmental factor in district coastal lowlands of Vietnam was taken as given, and vulnerability was analysed based only on variations in socio-economic attributes of individuals and social groups.

The main limitation of the socio-economic approach is that it focuses only on variations within society (i.e. differences among individuals or social groups). In reality, societies vary not only due to sociopolitical factors but also to environmental factors. Two social groups having similar socio-economic characteristics, but different environmental attributes can have different levels of vulnerability and vice versa. In general, this method overlooks or takes as exogenous the environment-based intensities, frequencies and probabilities of environmental shocks, such as droughts and floods. It also does not account for the availability of natural resource bases to potentially counteract the negative impacts of these environmental shocks. For example, areas with easily accessible underground water can better cope with droughts by utilising this resource.

3.2.2 Biophysical approach

The biophysical approach assesses the level of damage that a given environmental stress causes on both social and biological systems. For instance, the monetary impact of climate change on agriculture can be measured by modeling the relationships between climatic variables and farm income (Mendelsohn *et al*. 1994; Polsky and Esterling 2001; Sanghi *et al.* 1998). Similarly, the yield impacts of climate change can be analysed by modeling the relationships between crop yields and climatic variables (Adams 1989; Kaiser *et al.* 1993; Olsen *et al.* 2000). Other related impact assessment studies include the impact of climate change: on human mortality and health terms (Martens *et al.* 1999); on food and water availability (Du Toit *et al.* 2001; Xiao *et al.* 2002); and on ecosystem damage (Forner 2006; Villers-Ruiz and Trejo-Vázquez 1997). The damage is most often estimated by taking forecasts or estimates from climate prediction models (Kurukulasuriya and Mendelsohn 2008a; Martens *et al.* 1999) or by creating indicators of sensitivity by identifying potential or actual hazards and their frequency (Cutter *et al.* 2000).

Füssel (2007) identified this approach as a 'risk-hazard approach' and denoted the vulnerability relationship as: a hazard-loss relationship in natural hazard research; a dose-response or exposure-effect relationship in epidemiology; and a damage function in macroeconomics. Kelly and Adger (2000) referred to the biophysical approach as an 'end-point analysis' responding to research questions such as: 'What is the extent of the climate change problem?' and 'Do the costs of climate change exceed the costs of greenhouse gas mitigation?'

Although very informative, the biophysical approach has its limitations. The major limitation is that the approach focuses mainly on physical damages, such as impact on yield. For example, a study on the impact of climate change on yield can show the reduction in yield due to simulated climatic variables, such as increased temperature or reduced precipitation. In other words, these simulations can provide the quantities of yield reduced due to climate change, but they do not show what that particular reduction means for different people. A 50 percent reduction in yield due to climate change does not mean the same for poor and rich farmers. Poor farmers very often cannot cope with marginal changes in their yields or income, whereas richer farmers can buffer their loss (smoothen consumption, in technical terms) by depending on savings or the selling of some of their assets.

By the same token, research on climate change and malaria incidences analyses how climate change favours or disfavours the reproduction (expansion) of main mosquito species of malaria in different geographical settings (Martens *et al.* 1999). But these types of research do not distinguish between people who have access to medication or preventive measures (such as vaccination) and those people without. In general, the biophysical approach focuses on sensitivity (change in yield, income, health) to climate change and misses much of the adaptive capacity of individuals or social groups, which is more explained by their inherent or internal characteristics or by the architecture of entitlements, as suggested by Adger (1999).

3.2.3 The integrated assessment approach

The integrated assessment approach combines both socio-economic and biophysical approaches to determine vulnerability. The ‘hazard-of-place model’ (Cutter *et al.* 2000) is a good example of this approach, in which both biophysical and socio-economic factors are systematically combined to determine vulnerability. The vulnerability mapping approach (O’Brien *et al.* 2004) is another example in which both socio-economic and biophysical factors are combined to indicate the level of vulnerability through mapping.

Füssel (2007) and Füssel and Klein (2006) argued that the IPCC (2001) definition, which conceptualises vulnerability to climate as a function of adaptive capacity, sensitivity, and exposure, accommodates the integrated approach to vulnerability analysis. According to Füssel and Klein (2006), the risk-hazard framework (biophysical approach) corresponds most closely to sensitivity in the IPCC terminology. Adaptive capacity (broader social development) is largely consistent with the socio-economic approach (Füssel 2007). In the IPCC framework, exposure has an external dimension, whereas both sensitivity and adaptive capacity have an internal dimension, which is implicitly assumed in the integrated vulnerability assessment framework (Füssel 2007).

Even though the integrated assessment approach corrects the weaknesses of the other approaches, it also has its limitations. The main limitation is that there is no standard method for combining the biophysical and socio-economic indicators. This approach uses different data sets, ranging from socio-economic data sets (e.g. race and age structures of households) to biophysical factors (e.g. frequencies of earthquakes). These data sets certainly have different and yet unknown weights. Cutter *et al.* (2000), argued this analysis provides no common metric for determining the relative importance of the social and biophysical vulnerability, or for determining the relative importance of each individual variable. The other weakness of this approach is that it does not account for the dynamism in vulnerability. Coping and adaptation are characterised by a continual change of strategies to take advantage of opportunities (Campbell 1999; Eriksen and Kelly 2007); thus, this dynamism is missing under the integrated assessment approach. Despite its weaknesses, however, this approach has much to offer in terms of policy decisions. Thus, this study adopted this method to analyse the vulnerability of Ethiopian farmers to climate change.

3.3 Methods for measuring vulnerability to climate change

As can be seen from the previous discussion, there are many methods for analysing vulnerability to climate change, especially in the biophysical or impact assessment methods. The most common methods employed in vulnerability literature, namely the econometric and indicator methods, are discussed below.

3.3.1 Econometric method

The econometric method has its roots in the poverty and development literature. This method uses household-level socio-economic survey data to analyse the level of vulnerability of different social groups. The method is divided into three categories: vulnerability as expected poverty (VEP); vulnerability as low expected utility (VEU); and vulnerability as uninsured exposure to risk (VER) (Hoddinott and Quisumbing 2003). All three share common characteristics in that they construct a measure of welfare loss attributed to shocks.

3.3.1.1 Vulnerability as expected poverty

In the expected poverty frameworks, vulnerability of a person is conceived as the prospect of that person: becoming poor in the future if currently not poor; or the prospect of that person continuing to be poor if currently poor (Christiaensen and Subbarao 2004). Thus, vulnerability is seen as expected poverty and consumption (income) is used as a proxy for well-being. This method is based on estimating the probability that a given shock, or set of shocks, moves consumption by households below a given minimum level (e.g. consumption poverty line) or forces the consumption level to stay below the given minimum requirement if it is already below that level (Chaudhuri *et al.* 2002).

Using cross-section survey data of 1998, Chaudhuri *et al.* (2002) showed that although only 22 percent of the population in Indonesia was poor, as much as 45 percent of that population was vulnerable to poverty. Tesliuc and Lindert (2002) used cross-section survey data in 2000 from Guatemala to show that three-quarters of the total population that is poor have a vulnerability index of 0.67, which means that two out of three of the then poor households would still be poor in the coming period. One of the disadvantages of this method is that if estimations are made using a single cross section, one must make a strong assumption that cross-sectional variability captures temporal variability (Hoddinott and Quisumbing 2003).

3.3.1.2 Vulnerability as low expected utility

Ligon and Schechter (2002; 2003) defined vulnerability as the difference between the expected utility of consumption and the utility derived from some level of certainty-equivalent consumption at and above, which the household would not be considered vulnerable. Ligon and Schechter (2003) applied this method to a panel data set from Bulgaria in 1994 and found that poverty and risk play roughly equal roles in reducing welfare. The disadvantage of this method is that it is difficult to account for an individual's risk preference, given that individuals are ill informed about their preferences, especially those related to uncertain events (Kanbur 1987).

3.3.1.3 Vulnerability as uninsured exposure to risk

The VER method is based on *ex post* assessment of the extent to which a negative shock causes welfare loss (Hoddinott and Quisumbing 2003). In this method, the impact of shocks is assessed by using panel data to quantify the change in induced consumption. Skoufias (2003) employed this approach to analyse the impact of shocks on Russia. In the absence of risk-management tools, shocks impose a welfare loss that is materialised through reduction in consumption. The amount of loss incurred due to shocks equals the amount paid as insurance to keep a household as well-off as before any shock occurs. The disadvantage of this method is that in the absence of panel data sets, estimates of impacts, especially from cross-sectional data, are often biased and thus inconclusive.

3.3.2 Indicator method

The indicator method of quantifying vulnerability is based on selecting some indicators from a set of potential indicators and then systematically combining them to point out the levels of vulnerability. These levels of vulnerability may be analysed at: local (Adger 1999; Leon-Vasquez *et al.* 2003; Morrow 1999); national (O'Brien *et al.* 2004); regional (Leichenko and O'Brien 2001; Vincent 2004); and global scales (Brooks *et al.* 2005; Moss *et al.* 2001).

Two options are available for calculating the level of vulnerability using this method at any scale. The first is assuming that all indicators of vulnerability have equal importance and thus giving them equal weights (Cutter *et al.* 2000). The second method assigns different weights to avoid the uncertainty of equal weighting given the diversity of indicators used. In line with the second method, many methodological approaches have been suggested to make up for the weight differences of indicators. Some of these approaches include: use of expert judgment (Kaly and Pratt 2000; Kaly *et al.* 1999); principal component analysis (Easter 1999; Cutter *et al.* 2003); correlation with past disaster events (Brooks *et al.* 2005); and use of fuzzy logic (Eakin and Tapia 2008). Even though there are attempts in giving weights, their appropriateness is still dubious; because there is no standard weighting method against which each method is tested for precision. Luers *et al.* (2003:257) explained the weakness of the indicator approach as follows:

> While the indicator approach is valuable for monitoring trends and exploring conceptual frameworks, indices are limited in their application by considerable subjectivity in the selection of variables and their relative weights, by the availability of data at various scales, and by the difficulty of testing or validating the different metrics. Perhaps most importantly, the indicator approach often leads to a lack of correspondence between the conceptual definition of vulnerability and the metrics.

Table 5 shows different indicators and the scales at which they could be used. Identification of the types of indicators and attachment of the scale of analysis was done by the International Food Policy Research Institute (IFPRI) and the Center for Environmental Economics and Policy in Africa (CEEPA) climate change research team. As shown in this table, level of education or literacy rate is a household characteristic (HHC) that can be analysed at:

- the household (HH) level, by taking the education level of the head of a household;

- the district (D) level, by taking the average of the education levels of the head of the household in the district; or
- the national (N) level, by taking this average for the nation.

Similarly, soil conditions are biophysical (BP) characteristics that can be seen at different scales, starting from the household level to the national level. The references listed in the fourth column of Table 5 report different studies that are based on different characteristics at different scales.

Both the econometric and the indicator methods are adopted for this study. The vulnerability as expected poverty (VEP) method, discussed above under the econometric approach, is employed to analyse vulnerability at the household level. The integrated vulnerability assessment approach, one of the indicator-based assessment methods, is adopted to compare the level of vulnerability among the agriculture based administrative regions of Ethiopia.

Table 5: Indicators or proxy variables used in vulnerability analysis

Type of Indicator*	**Indicator**	**Scale of Analysis****	**Sources**
HHC	Level of education or literacy rate	HH, D, N	Kuhl 2004; Nyong *et al*. 2003; Paavola 2004; Brooks, Adger and Kelly 2005; Haan, Farmer and Wheeler 2001.
HHC	Age	HH	Nyong *et al*. 2003; Kuhl 2004; Haan, Farmer,and Wheeler 2001; Næss *et al.* 2006.
HHC	Labour unit/consumer unit	HH	Nyong *et al.* 2003.
HHC	Assets, land value and house value (standard)	HH, D	Moser 1998; Nyong *et al.* 2003; Aandahi and O'Brien 2001.
HHC	Household size and female-headed households	HH, D	Nyong *et al.* 2003; O'Brien *et al.* 2004; Paavola 2004; Kuhl 2004.
HHC	Drinking water source	HH	Aandahi and O'Brien 2001; Paavola 2004.
HHC	Household members	HH	Nyong *et al.* 2003.
HHC	Non-farm income and diversity of income sources	HH, D	Nyong *et al*. 2003; Adger 1996, 1999; Eakin 2002; Ford, Barry and Wandel 2006; Haan, Farmer and Wheeler 2001.
HHC	Food sufficiency	HH, D, N	Nyong *et al.* 2003.
HHC	Adjustment measures	HH	Ford, Barry and Wandel 2006.
BP	Soil conditions	HH, D, N	O'Brien *et al*. 2004.
BP	Current climate	HH, D, N	O'Brien *et al*. 2004.
BP	Vegetation	D, N	Haan, Farmer and Wheeler 2001.
INST	Social networks (member of group or association)	HH	Ford, Barry and Wandel 2006; Nyong *et al.* 2003.
INST	Institutional arrangements	D, N	Ford, Barry, and Wandel 2006; O'Brien *et al.* 2004.
FC	Livestock ownership	HH	Paavola 2004.
FC	Crop types, cropping systems (monocropping, multiple cropping), fertilizer consumption or input use	HH	Bantilan and Anupama 2002; Aandahi and O'Brien 2001.
FC	Irrigation rate and irrigation source	HH, D	Aandahi and O'Brien 2001; O'Brien *et al*. 2004.
BP	Drought and flood-prone areas	D, N	O'Brien *et al*. 2004.
ECO	Income level	HH	Adger 1996; Haan, Farmer, and
ECO	Percentage of households below poverty line	D	Wheeler 2001.
ECO	Food expenditure	HH	Aandahi and O'Brien 2001;
ECO	Infrastructure	HH, D, N	Adger 1996; Paavola 2004; O'Brien *et al*. 2004; Haan, Farmer, and Wheeler 2001.

Source: Nhemachena et al. (2006)

*Types of indicators: HHC = household characteristic; INST = institutional; FC = farm characteristic; BP = biophysical; ECO = economy.

**Scale of analysis: HH = household; D = district; N = national.

3.4 Approaches to assessing adaptation to climate change in agriculture

3.4.1 Adaptation

Adaptation and mitigation are the two options to reduce the negative impacts of climate change. Mitigation refers to reducing climate change damages by reducing the emissions of green house gasses. Adaptation to climate change refers to adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities (IPCC 2001). Even though mitigation targets uprooting the major causes of climate change and offers long run solutions, adaptation is necessary given the current state of the world. Füssel (2007) argues that a high emphasis should be given to adaptation mainly due to the facts that: human activities have already affected climate; climate change continues given past trends; the effect of emission reduction or mitigation takes several decades; and adaptation can be undertaken at local or national states as it is less dependent on the actions of others.

In agriculture, adaptation to climate change takes place at farm, national and global levels. Farm level adaptation depends on: technology (e.g. the availability of different varieties of crops and irrigation); soil types; and the capacity of farmers to detect climate change and undertake necessary actions (Maddison 2006; Kurukulasuriya and Mendelsohn 2008a; Hassan and Nhemachena 2008). National and global level adaptations depend on the identification of comparative advantages in the production of specific commodities in the face of climate change. The production of specific commodities depends on: local and international policy environments; world patterns of comparative advantages; and the responses of producers and consumers to the price signals of global markets (Schimmelpfennig *et al.* 1996; Bradshaw *et al.* 2004; Kurukulasuriya and Rosenthal 2003).

3.4.2 Approaches to assessing adaptation to climate change in agriculture

Approaches to measuring adaptation to climate change in agriculture are divided into two models. These are the partial and economy-wide (general equilibrium) models. Economy-wide models are analytical models, which look at the economy as a complete system of independent components (industries, factors of production, institutions and the rest of the world). Partial equilibrium models alternatively are based on the analysis of part of the overall economy such as a single market (single commodity) or subsets of markets or sectors (Sadoulet and De Janvry 1995). In agriculture, partial equilibrium models mainly analyze adaptation at farm or household levels (Maddison 2006; Kurukulasuriya and Mendelsohn 2008a, 2008b; Hassan and Nhemachena 2008) whereas general equilibrium models are employed to analyse the impact and adaptation at national or global levels (Darwin *et al.* 1995; Winters *et al.* 1996; Yates and Strzepek 1998 Nodrhaus and Yang 1996; Deke *et al.* 2001; Roson 2003).

3.4.2.1 Economy–wide models for analysing adaptation to climate change

Computable General equilibrium (CGE) models are one of the many economy-wide economic policy assessment models extensively used in environmental economics and policy analysis (Oladosu *et al.* 1999; Roson 2003). This class of economic models is suitable for environmental issues as it is capable of capturing complex economy-wide effects of exogenous changes while at the same time providing insights into micro level impacts on producers, consumers and institutions (Mabugu 2002; Oladosu et al. 1999). Moreover, CGE models provide more accurate, realistic and consistent pictures of the economic systems (Roson 2003).

Nordhaus and Yang (1996) employed a CGE model to analyse the different national strategies in climate change policies such as: pure market solutions; efficient cooperative outcomes; and non-cooperative equilibrium. They indicated that the high income countries could be the major losers from cooperation. Deke *et al*. (2001) used the CGE approach to analyse adaptation to climate change in different regions of the world. The said study result showed that vulnerability to climate impact differs significantly across regions and that the overall adjustment of the economic system reduces the direct economic impacts. Using a global CGE approach, Roson (2003) analysed the impact of climate change on health and loss associated with sea level rise. Study results from Roson (2003) showed that the industries and countries most negatively affected by climate shocks are those that have labour-intensive or land-intensive production processes. Winters *et al.* (1996) studied the impact of global climate change on the less developed countries using a CGE model for three economies representing the poor cereal importing countries of Africa, Asia and Latin America. The said study showed that all these countries would suffer damages and that their agricultural outputs would fall as a result of climate change and that Africa would be the most severely affected. Yates and Strzepek (1998) also used a CGE model to assess the impact of climate change on the Egyptian economy and concluded that the net effects of climate change on per capita GDP were not significant.

Although CGE models can analyse the economy-wide impacts and adaptation to climate change, there are some drawbacks in using them. Key limitations include: difficulties with model selection; parameter specification and functional forms; data consistency or calibration problems; the absence of statistical tests for the model specification; integration of environmental dimensions in the model; and the complexity and requirement of skill to develop and use CGE models (Gillig and McCarl, 2002; Roson, 2003).

3.4.2.2 Partial equilibrium models for analysing adaptation to climate change

There are three sets of approaches under the partial equilibrium models for analysing adaptation to climate change. These are the agronomic-economic, cross sectional and discrete choice models.

3.4.2.2.1 Agronomic-economic models

Agronomic-economic models analyse the relationships between crop yields and climatic factors such as temperature and rainfall. In addition to analysing the relationships between climatic factors and crop yields, these models incorporate the effects of farm management (adaptation) options such as: the timing of field operations; crop choices; and the amount of irrigation on yield (Adams 1989; Kaiser *et al.* 1993; Chang 2002).

Kaiser *et a.l* (1993) combined agronomic and economic models to analyse the adaptation to climate change by taking the case of crop farmers in southern Minnesota. The results from the study revealed that farmers in southern Minnesota can effectively adapt to climate change by adopting late maturing cultivars, changing crop mix and altering the timing of field operations. Chang (2002) combined yield response and economic models to analyse adaptation to climate change in Taiwan and showed that climate change could be beneficial with adaptation practices in place.

Although this approach enables the detailed understanding of the physical and biological responses, as well as the adjustments farmers make in response to changing climatic and other conditions, it has limitations. Due to the very high cost associated with experimentation, limited test sites and crop types are affordable. The limitation of test sites and crop types due to the associated costs hinders the possibility of analysing the impact and adaptation to climate change over diverse agro-ecological settings. This undermines the possibility of using results at a national level.

3.4.2.2.2 Cross- sectional models

The Ricardian approach is the most extensively used cross-sectional approach to analyse the impact of climate change by incorporating adaptation. The Ricardian model analyzes a cross section of farms under different climatic conditions to examine the relationship between the value of land or net revenue and the agro-climatic factors (Kurukulasuriya and Mendelsohn 2008a; Seo and Mendelsohn 2008; Deressa *et al.* 2005; Mendelsohn *et al.* 1994; Nhemachena 2009; Seo *et al.* 2009).

Seo and Mendelsohn (2008) adopted the Ricardian approach to examine the impact of climate change on animal husbandry and the way farmers adapt. They showed that large livestock farms in Africa are more sensitive to temperature than small ones, primarily because of their dependence on cattle. Kurukulasuriya and Mendelsohn (2008a) examined the impact of climate change on croplands in Africa by using a Ricardian approach. They indicated that current and future climatic conditions do affect the net revenues of farms across

Africa. Deressa *et al*. (2005) used a Ricardian model to estimate climate change impacts on sugarcane production in South Africa. The study was based on a time series data set for the period 1977-1998. The results show that predicted changes in temperature strongly affected net revenue from sugarcane production compared to changes in precipitation. Nhemachena (2009) measured the aggregate impact of climate change on income from all agricultural production systems (crop, livestock and mixed) in Africa and predicted future impacts under various climate scenarios. The results showed that the small-scale mixed crop and livestock system predominant in Africa is the most tolerant system, whereas specialised crop production is the most vulnerable to warming and lower rainfall. The results further indicated that farming systems located in dry semi-arid and arid regions (for example most southern parts of the continent) will suffer most from increases in warming and drying compared to more humid regions.

The most important advantage of the Ricardian model is its ability to incorporate private adaptations. Farmers adapt to climate change to maximize profit by changing the crop mix, planting and harvesting dates, and a host of agronomic practices. The farmers' response involves costs that cause economic damages that are reflected in net revenue. Thus, to fully account for the cost or benefit of adaptation the relevant dependent variable should be net revenue or land value (capitalised net revenues) and not yield. Accordingly, the Ricardian approach takes adaptation into account by measuring economic damages as reductions in net revenue or land value induced by climatic factors. The other advantage of the model is that it is cost-effective, since secondary data on cross-sectional sites can be relatively easy to collect on climatic, production and socio-economic factors.

The weaknesses of the Ricardian approach are: it is not based on controlled experiments across farms and it does not include price effects and carbon fertilization effects (Cline 1996).

3.4.2.2.3 Discrete choice models

The use of discrete choice models in climate change adaptation research is a relatively new approach. It is based on the conceptual similarities between agricultural technology adoption, climate change adaptation and other related models involving decisions to whether to adopt or not adopt.

Agricultural technology adoption models are based on farmers' utility or profit maximizing behaviours (Norris and Batie 1987; Pryanishnikov and Katarina 2003). The assumption here is that farmers adopt a new technology only when the perceived utility or profit from using this new technology is significantly greater than the traditional or the old method. While utility is not directly observed, the actions of economic agents are observed through the choices they make.

Probit and logit models are the most commonly used empirical models for analysis of agricultural technology adoption. Binary probit or logit models are employed when the number of choices available are two (whether to adopt or not). The extensions of these models, most often referred to as multivariate models, are employed when the number of choices available are more than two. The most commonly cited multivariate choice models in unordered choices are multinomial logit (MNL) and multinomial probit (MNP) models. Multivariate choice models have advantages over their counterparts of binomial logit and probit models in two aspects (Wu and Babcock 1998). Firstly, they allow exploring both factors, conditioning specific choices or combination of choices. Secondly, they take care of self- selection and interactions between alternatives.

These models have also been employed in climate changes studies due to the conceptual similarities in agricultural technology adoption and climate change studies. For example, Nhemachena and Hassan (2007) employed the multivariate probit model to analyse factors influencing the choice of climate change adaptation options in Southern Africa. Kurukulasuriya and Mendelsohn (2008b; 2008c) and Hassan and Nhemachena (2008), employed the multinomial logit model to see if the choice of crop by farmers is climate sensitive. Similarly Seo and Mendelsohn (2006) and Seo *et al.* (2009) used the multinomial logit model to analyse how the choice of livestock species is climate sensitive. Additionally, Bryan *et al.* (2009) adopted the probit model to analyze the factors influencing the decision to adapt to climate change by using data from a survey of 1800 farm households in South Africa and Ethiopia.

Moreover, when decisions are made by farmers to adopt a new technology it requires a couple of steps. Models with two-step regressions are employed to correct the selection bias generated during the decision making processes. For instance William and Stan (2003) employed the Heckman's two-step procedure to analyse the factors affecting the awareness and adoption of new agricultural technologies in the United States of America.

In the William and Stan (2003) study, the first stage is the analysis of factors affecting the awareness of new agricultural technologies and the second stage is adoption of the new agricultural technologies. Similarly Yirga (2007) and Kaliba *et al*. (2000) employed the Heckman's selection model to analyse the two-step processes of agricultural technology adoption and the intensity of agricultural input use. Moreover, Kurukulasuriya and Mendelsohn (2007) adopted the Heckman's selection model to examine how climate affects the decision to employ irrigation in the first stage and how climate affects the net revenues of dryland and irrigated land in the second stage.

The study by Maddison (2006) argued that adaptation to climate change is a two-step process which involves perceiving that climate is changing in the first step and then responding to changes through adaptation in the second step. To this effect, Maddison (2006) also employed the Heckman's sample selection method to analyse the perception of and adaptation to climate change in Africa. Similarly, Gbetibouo (2009) used the Heckman's sample selection method to study the factors that affect the perception of and adaptation to climate change in the Limpopo River Basin of South Africa. This study adopts the Heckman's two-step procedure (Heckman 1976) to analyse the perception and adaptation to climate change in the Nile Basin of Ethiopia.

3.5 Summary

This chapter described the conceptual and methodological approaches to vulnerability assessment. Three conceptual approaches to assessing vulnerability to climate change have been identified. These are: the socio-economic, biophysical and integrated vulnerability assessment approaches. The socio-economic assessment approach mainly focuses on the social aspects of vulnerability where as the biophysical vulnerability assessment approach focus on the natural side. The integrated vulnerability assessment approach combines both the socio-economic and biophysical approaches to assessing vulnerability to climate change. This chapter has also discussed the two major methodological approaches to assessing vulnerability which are the econometric and the indicator approaches along with the strengths and weaknesses of each method.

Definition of adaptation, the different levels at which adaptation takes place and approaches to analysing adaptation to climate change have also been discussed. Adaptation to climate change has been defined as the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities (IPCC 2001). Is has also been indicated that adaptation takes place at different levels: the farm level; the household level; the national level; and the regional level. The different methodological approaches to analysing adaptation to climate change have also been discussed.

Two methodological approaches are found in analysing adaptation to climate change. These are the general and partial equilibrium models. The general equilibrium models deal with whole parts of the economy whereas the partial equilibrium models deal with a part of the overall economy. Computable general equilibrium models are the most frequently used models in dealing with climate change adaptation and the overall economy. The partial equilibrium models employed in the adaptation analysis include: the agronomic-economic; cross-sectional; and the discrete choice models.

This study analyses both the vulnerability of Ethiopian farmers to climate change and the actions they take to adapt to climate change to reduce its negative impact. Vulnerability of Ethiopian farmers to climate change is analysed both at the household and regional levels. For the household level analysis, the vulnerability as expected poverty (VEP) approach is adopted. The integrated vulnerability assessment approach is employed to analyse vulnerability at the regional level. The Heckman probit model is also employed to analyse the two-step processes of perception and adaptation to climate change in the Nile Basin of Ethiopia.

CHAPTER 4

VULNERABILITY ASSESSMENT AT HOUSEHOLD AND REGIONAL LEVELS

4.1 Introduction

This chapter analyses the vulnerability of Ethiopian farmers to climate change at household and regional levels. The first section assesses vulnerability to climate change at the household level. Section two presents vulnerability assessment at region level. Section three presents a summary of this chapter.

4.2 Assessing household vulnerability to climate change: The case of farmers in the Nile Basin of Ethiopia

4.2.1 Empirical model

As discussed in chapter three, this study adopted the vulnerability to expected poverty (VEP) approach to analyse vulnerability. This approach is based on the similarities and differences between poverty and vulnerability. The similarities are that both of them are exacerbated by shocks (covariate and idiosyncratic) and are also measured against a threshold level of welfare that can sustain life under different circumstances. The main difference is that while poverty is an *ex post* (backward looking) concept, vulnerability is an *ex ante* or a foreword looking concept. Poverty is an *ex post* concept in that a household's (individual's) observed poverty status is based on whether or not the household's level of consumption is above or below a preselected poverty line. Vulnerability looks forward (expected poverty) in that it assists in knowing that a household will, if currently not poor, fall below a poverty line or if currently poor, will remain in poverty. The knowledge of who will be at risk of becoming poor in the future will assist poverty prevention and reduction in the future.

The assessment of household's vulnerability requires the estimation of its expected consumption and the variance of its consumption. These types of estimations require the use of longitudinal data sets (where the same households are tracked over a number of periods) which enable the estimation of inter-temporal variance of consumption at the household level without the need for auxiliary assumption (Chaudhuri *et al.* 2002). Mainly due to the high costs of data collection, longitudinal data sets are rarely found in developing countries, leaving the option of using only cross-sectional data sets. Given this fact, Chaudhuri *et al.* (2002) developed an approach that enables the use of cross-section data sets to measure vulnerability by assuming temporal variations to be explained by cross-sectional variations. Other studies have also followed this approach given the data constraints in developing countries (Shewmake 2008; Tesliuc and Lindert 2002; Sarris and Karfakis 2006).

Similarly, this study analyses the vulnerability of households in the Nile Basin of Ethiopia by making use of a cross-section data set collected from the Nile Basin of Ethiopia during the 2004/ 2005 production season. The assumption here is that experiencing climatic shocks such as droughts, floods and hailstorms will increase the probability of farmers falling below a given consumption / income level or force them to stay under, if already under this level.

This method is based on the Chaudhuri *et al.* (2002) stochastic process, generating the consumption of a household *h* as given by:

$$\ln C_h = X_h\beta + e_h \tag{4.1}$$

Where C_h is per capita consumption[1] expenditure, X_h represents a bundle of observable household characteristics (such as household size, location, educational attainment of the household head etc.) and climatic shocks namely droughts, floods and hailstorms. β is a vector of parameters, and e_h is a mean zero disturbance term.

Assume that the variance of e_h is given by:

$$\sigma_{e,h}^{\ 2} = X_h\theta \tag{4.2}$$

β and θ are parameter estimates from a three-step feasible generalised least squares (FGLS) procedure suggested by Amemiya (1977).

[1] For this study, the income of farmers is considered instead of consumption. It is assumed that the majority or all of the farmers' incomes are consumed in poor countries like Ethiopia. In other words, they do not save.

Using the estimates β and θ, the expected log of consumption and variance of log consumption for each household *h* are, respectively, estimated as:

$$\hat{E}\left[\ln C_h \mid X_h\right] = X_h \hat{\beta} \quad (4.3)$$

$$\hat{V}\left[\ln C_h \mid X_h\right] = \hat{\sigma}^2_{e,h} = X_h \hat{\theta} \quad (4.4)$$

By assuming that log consumption is normally distributed (i.e. that $\ln C_h$ is normally distributed), the above enables the estimation of the probability that a household with the characteristics X_h will be poor (i.e. the household's vulnerability level). Letting $\Phi(.)$ denote the cumulative density of the standard normal, the estimated probability is given by:

$$\hat{V}_h = \hat{\Pr}(\ln C_h < \ln z \mid X_h) = \Phi\left(\frac{\ln z - X_h \hat{\beta}}{\sqrt{X_h \hat{\theta}}}\right) \quad (4.5)$$

Where *ln z* is the log of the minimum consumption/ income level beyond which a household would be called vulnerable.

4.2.2 Study area

The Nile Basin of Ethiopia was chosen as the study area for this research. The Nile Basin of Ethiopia extends to about 358,889 km^2, which is equivalent to 34% of the total geographic area of the country. About 40% of the country's population lives in this basin, which covers six different regional states of Ethiopia with different proportions? It covers 38% of the total land area of Amhara, 24% of Oromiya, 15% of Benishangul-Gumuz, 11% of Tigray, 7% of Gambella and 5% of Southern Nations Nationalities and Peoples (SNNP) (MoWR 1998).

There are three major rivers in the basin namely:

- the Abbay River, which originates from the central highlands;
- the Tekezé River, which originates from the north-western parts 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% of all water supplied by Ethiopia's 12 river basins (MoWR 1998).

The surveyed households in the Nile Basin of Ethiopia fall under three of the five traditional agro-ecological settings in Ethiopia. For instance, the Bereh Aleltu district is located in Dega, whereas the Wonbera and Limu districts are located in the Kola and Weyanadega agro-ecological settings, respectively.

4.2.3 Data sources

The data used for this study is obtained from a household survey of farmers during the 2004/2005 production year in the Nile Basin of Ethiopia. The International Food Policy Research Institute (IFPRI) in collaboration with the Ethiopian Development Research Institute (EDRI) conducted this cross-section survey. Sample districts were purposively selected to include different attributes of the basin, which included: traditional typology of agro-ecological zones in the country; a degree of irrigation activity (percent of cultivated land); average annual rainfall; and rainfall variability and vulnerability (food aid dependent population).

Peasant administrations (PA's) from each district were also purposively selected to include households who irrigate their farms. One peasant administration was selected from every district making both the number of districts and peasant administrations to be 20. The inclusion of peasant administrations, which included farmers irrigating their farms, led to the selection of 162 villages (*gots*). Fifty farmers were randomly selected from each peasant association, making the total number of households interviewed to be 1000. Out of the 20 districts surveyed, three districts are found in Tigray, six in Amhara, seven in Oromia, three in Benehangul Gumz and one in SNNP regional states. Table 6 summarises the distributions of sampled villages.

The collected data that is covered include: household characteristics; incidences of different climatic conditions and other shocks over the past five years; food aid; land tenure; machinery ownership; rain-fed and irrigated agriculture; livestock production; access to credit; market and extension; expenditure on food; income; perceptions of climate change; adaptation options; and social capital. Moreover, temperature and rainfall data for the surveyed seasons were obtained from a global climate database developed by the University of East Anglia (Mitchell and Jones 2005). The surveyed districts with their agro-ecological classifications are displayed below in Figure 5

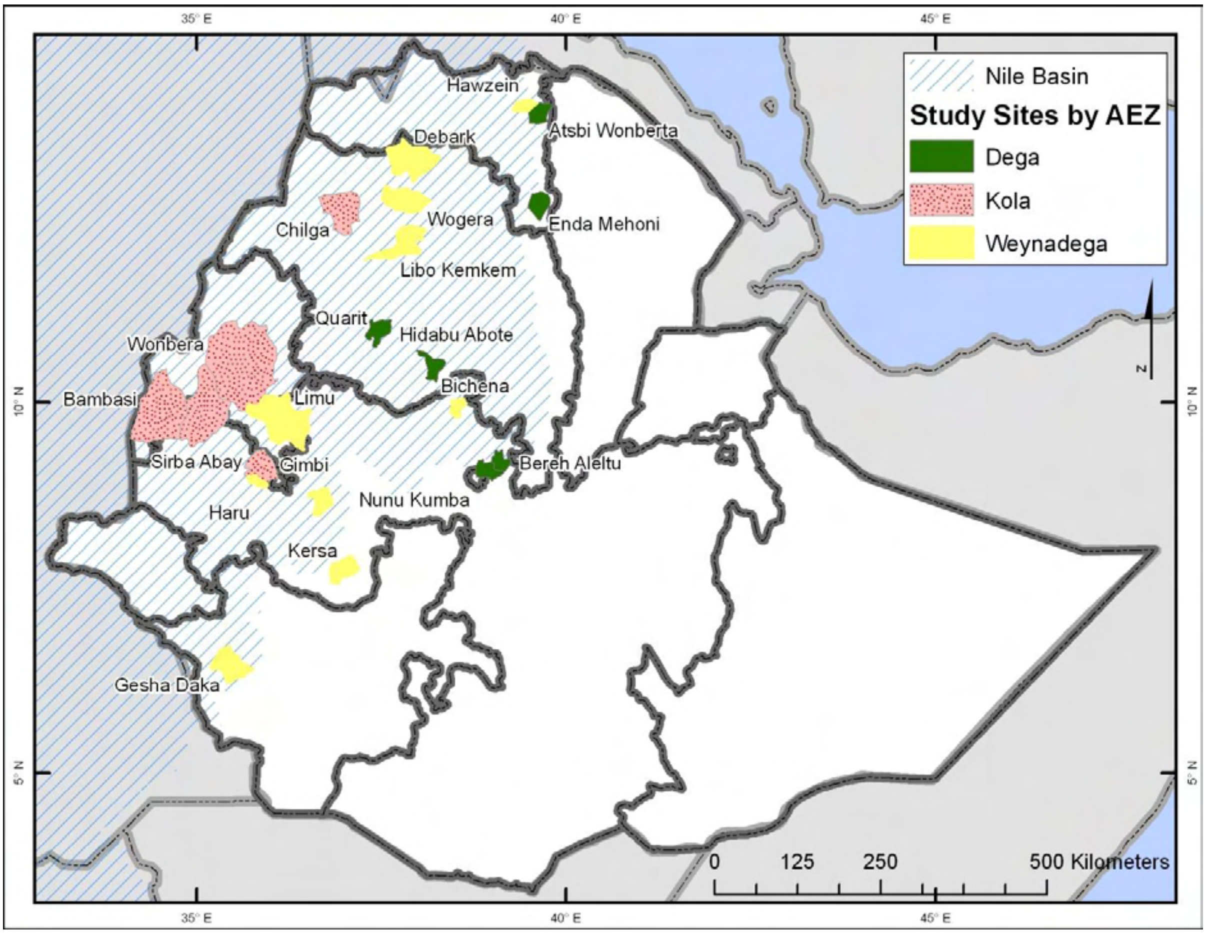

Figure 5: Surveyed districts along with their agro-ecological settings in the Nile Basin of Ethiopia

Table 6: Distribution of sampled villages

Region	Zone	District (Woreda)	Peasant Admin. (Kebele)	Number of villages
Tigray	EastTigray	Hawzein	Selam	7
		Atsbi Wonberta	Felege Woinie	9
	South Tigray	Endamehoni	Mehan	3
Amhara	North Gondar	Debark	Mekara	19
		Chilga	Teber Serako	10
		Wogera	Sak Debir	9
	South Gondar	Libo Kemkem	Angot	9
	East Gojam	Bichena	Aratband Bichena	11
	West Gojam	Quarit	Gebez	9
Oromia	West Wellega	Gimbi	Were Sayo	9
		Haru	Genti Abo	12
		Bereh Aleltu	Welgewo	5
		Hidabu Abote	Sira marase	10
	East Wellega	Limu	Areb Gebeya	11
		Nunu Kumba	Bachu	12
	Jimma	Kersa	Merewa	6
Benishangul-Gumuz	Metekel	Wonbera	Addis Alem	1
	Asosa	Bambasi	Sonka	1
	Kamashi	Sirba Abay	Koncho	1
SNNP	Zone 1	Gesha Daka	Kicho	8
Total				162

4.2.4 Selected socio-economic and climatic conditions in the study districts

4.2.4.1 Household characteristics

The size of a family in the study is generally high with an average of 6.15 persons. The average age of household heads was 44 years and most of them were found to be male. Most of the respondents do not read and write as only a third of them had formal educations ranging from 1 to 12 years. The majority of the respondents are from the Oromo ethnic groups followed by Amhara. As in the case of many African traditional societies, many of the respondents were involved in many social activities and networkings with relatives and non-relatives that involved resource, work and information sharing. For instance, the number of relatives in a *got* (village), which is a proxy for social capital, was 13.4 persons on average (Table 7).

Table 7: Basic household characteristics of the surveyed farmers

	Mean	Standard Deviation
Years of education	1.70	2.78
Size of household	6.15	2.22
Gender of the head of household	0.89	0.31
Age of the head of household	44.29	12.62
Number of relatives in *got*	13.4	19.44

The surveyed households were generally poor in terms of income and ownership of assets. The income from their farms was very low with an average of 4356.2[2] Ethiopian Birr per year as the majority of the respondents were subsistence farmers. Additionally, off-farm job-opportunities were generally limited as only 24 percent of the sampled households had access to off-farm activities and earned on average 218 Birr per year. Only 13 percent of the respondents lived in residences made of stone, concrete or brick. The remaining 87 percent lived in low cost houses made of wood and wood products, while their roofs were made of iron sheets, grass or mud. Moreover, less than a third of the households had access to toilet facilities (Table 8). Average land holding is very small given the high population pressure indicating a need for better technology to feed the ever-growing population.

Table 8: Basic assets of the respondents

	Average	Percentage of farmers
Farm’s income in Ethiopian Birr	4356.20	
Off-farm income in Ethiopian Birr	218.00	
Access to off-farm employment		24%
Access to good quality housing		13%
Access to toilet facilities		31.2%
Land holding in hectares	2.02	

Given that the subsistence and mixed crop-livestock production system is the dominant production system, livestock keeping was common among the surveyed farmers. Livestock keeping is very important in substance agriculture as it serves as the source of power for

[2] equal to 445 US dollars per year

traction, food and soil management, because it provides manure. Therefore, about 95 percent of the surveyed households own livestock.

Basic services and infrastructure are generally poor in the surveyed districts as is the case with the rest of the country. For instance, about half of the respondents had access to agricultural extensions and less than a quarter of them had access to credit facilities. While about half of the surveyed farmers had access to a landline telephone, only a few of them had access to electricity. Additionally, these farmers were so far scattered and remote that they have to travel long distances to reach input and output markets (Table 9).

Table 9: Access to basic services and infrastructure

	Percentage of respondents	Average
Access to agricultural extension	55.00	
Access to formal/informal credit	22.00	
Access to a landline telephone	47.40	
Access to electricity	17.80	
Distance to input markets (Km)		5.61
Distance to output markets (Km)		5.70

4.2.4.2 Climatic conditions, shocks and coping strategies

As described earlier, the survey districts are located in thee agro-ecological settings, which differ in many ways. Two of the major attributes that characterise their differences are temperature and rainfall. As expected, Kola agro-ecology is the hottest and driest whereas Dega is the wettest and coolest of all. Table 10 describes the average temperature and precipitation across agro-ecological settings.

Table 10: Annual average temperature and rainfall across the surveyed agro-ecologies

Agro-ecology	Average temperature	Average rainfall
Kola	22.00	93.42
Weynadega	17.70	113.84
Dega	17.30	119.10
Total	18.63	111.44

The surveyed households also reported to have encountered many environmental shocks mainly droughts, floods and hailstorms. Over the previous five year period, the households reported that 31% of the shocks were droughts, 12% were floods and 18% were hailstorms (Table 11). The relatively high frequency of drought-affected households is consistent in Ethiopia as it a drought-prone country. These shocks resulted in a variety of reported losses, primarily consisting of crop yield declines and asset/income losses (Table 12). The majority of farmers did nothing to respond to these shocks, mainly due to poverty.

Table 11: Major shocks encountered by surveyed farmers

Shock	Number of farmers	Percentage of farmers
Drought	380	31.00
Hailstorm	225	18.30
Flood	142	11.60
Animal disease	112	9.10
Damage to crops before harvest	84	6.80
An Illness of a family member	71	5.80

Table 12: Effects of shocks on surveyed farmers

Result	Number of farmers	Percentage of farmers
Decline in crop yield	403	32.80
Loss of assets	213	17.40
Loss of income	201	16.40
Food insecurity/shortage	140	11.40
Death of livestock	128	10.40
Decline in consumption	124	10.10

In general, most of the surveyed farmers who reported to have experienced shocks over the past five years sold livestock to cope. This suggests that, in addition to serving as a source of power for farming (e.g. oxen) and manure for fertilizing soil, livestock can serve as assets and insurance against shocks (Yirga 2007). The other utilised coping strategies included: borrowing from relatives; eating less; depending on food aid and food-for-work; and looking for off-farm employment. Figure 6 describes the types of coping strategies employed under different climatic shocks by a percentage of farmers who used a coping strategy.

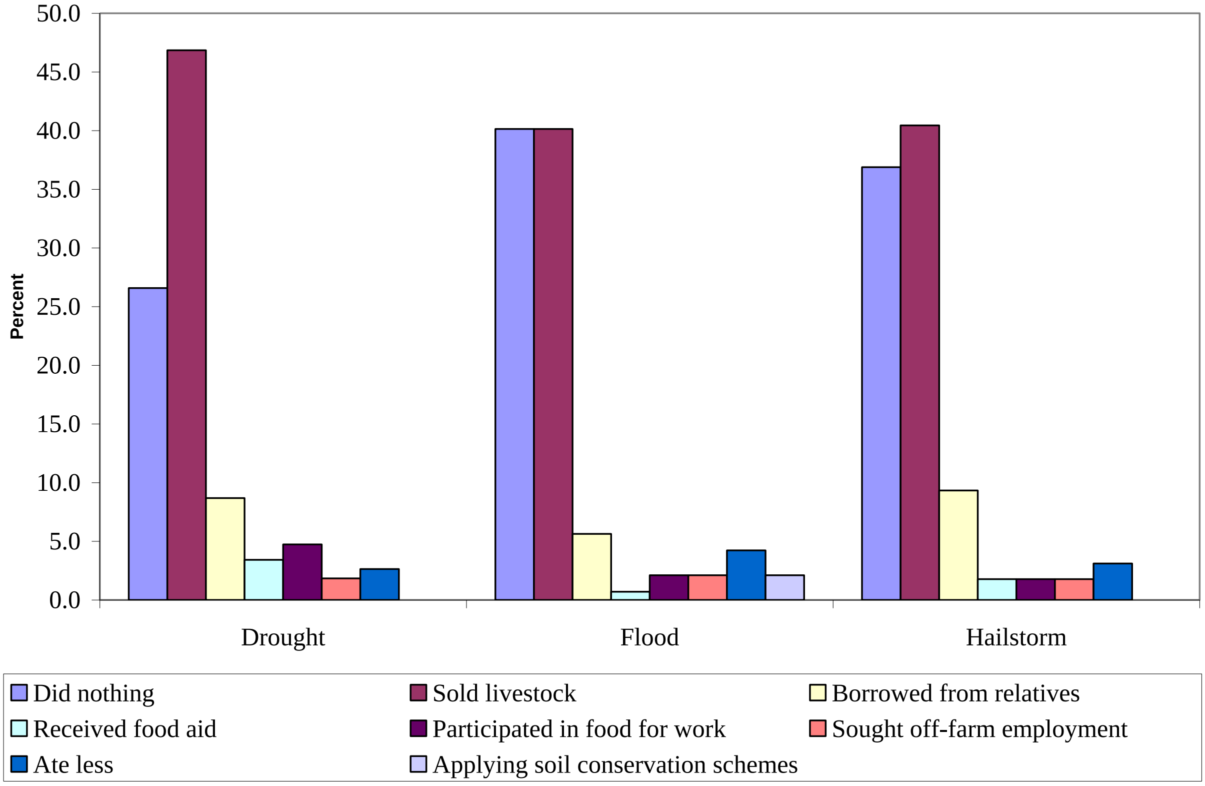

Figure 6: Coping strategies to major environmental shocks

4.2.5 Model variables and econometric estimation

As indicated earlier (in section 4.2.1), the estimation of households' vulnerability to poverty requires the estimation of both the expected value and variance of consumption. By taking income to proxy consumption, the expected value and variance of income were estimated. Different socio-economic and environmental factors were included as explanatory variables in the estimation procedure.

Socio-economic factors in the empirical model include the: years of education of the head of the household; size of the household; gender and age of the head of the household; livestock ownership; farm size in hectares; access to agricultural extension and credit facilities; and distance to input and output markets. Environmental factors include: the average temperature and rainfall for the 2004/2005 years' crop season; the major shocks reported over the past five years; and the agro-ecological settings. Incidences of major shocks were included as they affect the expected value and variance of income. Dummy variables for agro-ecology were included to control the differences across agro-ecological systems whereas regional dummies were included to control the regional variations across the Nile Basin of Ethiopia. These factors were selected based on literature on similar vulnerability to poverty studies (Shewmake 2008; Tesliuc and Lindert 2002; Sarris and Karfakis 2006).

The explanatory variables selected for this study have been shown to affect the expected value and variance of consumption or income in many models estimating vulnerability to poverty (Chaudhuri *et al.* 2002; Tesliuc and Lindert 2002; Sarris and Karfakis, 2006; Shewmake 2008). Table 13 presents a summary of the explanatory variables used in this study.

Table 13: Explanatory variables used in the empirical analysis

Explanatory variables	**Description**
Droughts	Dummy, takes the value of 1 if occurred during the prior five years, and 0 otherwise
Floods	Dummy, takes the value of 1 if occurred during the prior five years, and 0 otherwise
Hailstorms	Dummy, takes the value of 1 if occurred during the prior five years, and 0 otherwise
Education for household head	Number of years
Size of household	Number of people in the household
Gender of household head	Dummy, takes the value of 1 if male and 0 otherwise
Age of household head	Years
Livestock ownership	Dummy, takes the value of 1 if owned and 0 otherwise
Use of crop and livestock extension services	Dummy, takes the value of 1 if visited and 0 otherwise
Credit access	Dummy, takes the value of 1 if there is access (formal/informal) and 0 otherwise
Farm size	In hectares
Distance to input and output markets	In kilometers
Amhara region	Dummy, takes the value of 1 if Amhara region and 0 otherwise
Oromia region	Dummy, takes the value of 1 if Oromia region and 0 otherwise

Beneshangul region	Dummy, takes the value of 1 if Beneshangul region and 0 otherwise
South Peoples' region	Dummy, takes the value of 1 if South Peoples' region and 0 otherwise
Temperature	Annual average over the 2004–2005 survey period in degrees centigrade
Rainfall	Annual average over the 2004–2005 survey period in millimeters
Local agro-ecology is Kola	Dummy, takes the value of 1 if Kola and 0 otherwise
Local agro-ecology is Weynadega	Dummy, takes the value of 1 if Weynadega and 0 otherwise
Local agro-ecology is Dega	Dummy, takes the value of 1 if Dega and 0 otherwise

4.2.6 Model results and discussion

4.2.6.1 Vulnerability analysis at basin and agro-ecological levels

The probability of a household falling below a given level of income (poverty line) was estimated based on different assumptions about the values of poverty line and vulnerability threshold levels. The choice of poverty line was based on assumptions such as the international poverty line of 1.25 US per day (World Bank 2008) and arbitrary values above and below the average income of the surveyed households. The vulnerability threshold (cutoff point) was arbitrarily chosen to be 0.5 following Chaudhuri *et al.* (2002) and Shewmake (2008). For instance a household which has a vulnerability value of 0.5 has a 50 percent chance of becoming poor in the future.

The results are plotted in Figures 7 and 8. The x-axis shows the observed and imputed values for the natural log of income, while the y-axis shows the computed estimates of vulnerability. Each graph is broken into four sections. Those in the upper left were poor in 2004/2005 and were likely to be the following year. While those in the bottom left were poor in 2004/2005, but have characteristics suggesting they have a less than 50 percent chance of being poor in the following year. Those in the upper right corner are not below the income threshold in 2004/2005 (vertical lines which indicate poverty lines), but were likely to become so in the following year, while those in the bottom right were above the income threshold and were likely to remain above it in 2005/2006.

Vulnerable (would be poor) households are located in the upper left and upper right sides of each figure, given the vulnerability threshold probability level of 0.5. These were the poor and likely to remain poor and the not poor and likely to become poor the following year. A closer look at Figures 7 and 8 shows that the majority of households who were poor remain poor and those who were not poor were likely to become poor the following year.

Table 14 gives the mean vulnerability levels of the surveyed households at basin level and across agro-ecological settings using different scenarios of poverty lines. When the poverty line is fixed at 2 US dollars per day, the majority (93 percent) of the surveyed households were vulnerable, whereas only 7 percent of them were identified as vulnerable when the poverty line is fixed at 0.3 US dollars per day. This indicates that the number of vulnerable households increases with increasing the minimum income level required to sustain daily life.

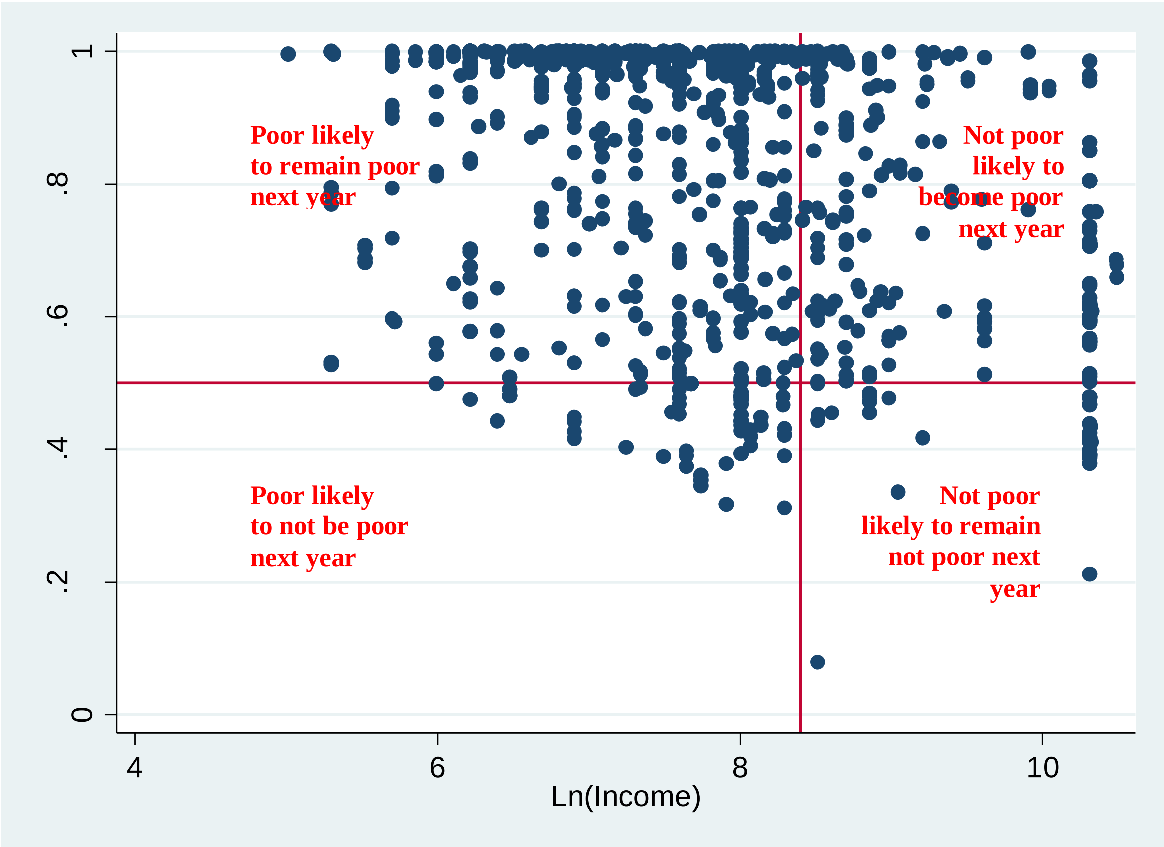

Figure 7: Vulnerability (income at 1.25 USD per day or 4471 Ethiopian Birr per year) plotted against Ln (income)

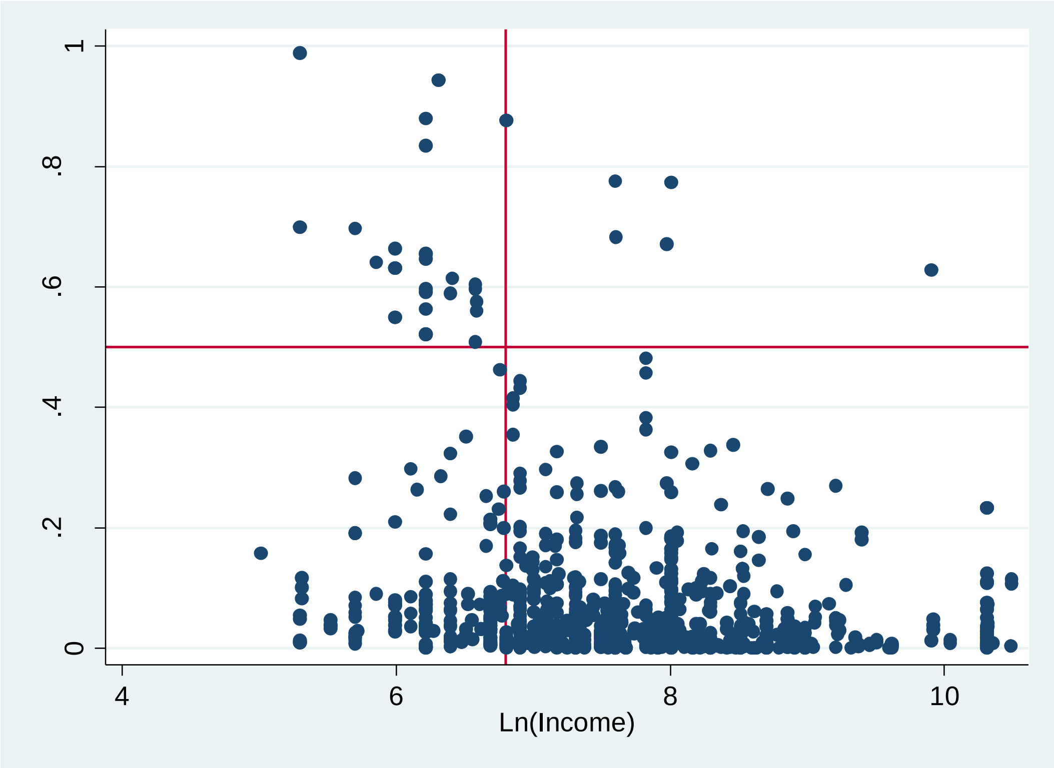

Figure 8: Vulnerability (income at 0.3 USD per day or 900 Ethiopian Birr per year) plotted against Ln (income)

The analysis undertaken to compare the vulnerability of households across different agro-ecologies for the different scenarios of poverty line indicate that farmers living in Kola were the most vulnerable to climatic extremes. This is depicted under columns 3-5 of table 14.

Table 14: Vulnerability at basin level and across agro-ecological settings using different scenarios of poverty lines

Scenario ($US per day)	Nile Basin	Kola	Weyandega	Dega
2.00	0.93	0.97	0.91	0.93
1.50	0.86	0.94	0.85	0.82
1.25	0.84	0.93	0.82	0.76
0.30	0.07	0.11	0.08	0.02

4.2.6.2 Vulnerability by household characteristics

Results show that vulnerability varies across different households' socio-economic characteristics and the types of climate extreme events experienced (Tables 15 and 16). For instance, a drought increases the probability of a household falling below a given level of income (poverty line) more than floods and hailstorms in the Nile Basin of Ethiopia under all scenarios. Results also show that household characteristics associated with poverty increase vulnerability. For example, households with a level of education less than the sample average are more vulnerable than households with a level of education more than the sample average, whereas female-headed households are more vulnerable than male-headed households. Moreover, older heads of households are more vulnerable than younger heads of households. Households who do not own livestock are more vulnerable than households who own livestock. Alternatively, there is no significant difference in the levels of vulnerability across different sizes of households, indicating a need to further look at the quality of household members than numbers of households as the determinant of vulnerability. Moreover, the different sizes of farms do not significantly affect vulnerability to climate extreme events. This indicates the need to focus on the quality of land rather than on the quantity in affecting vulnerability to climate extreme events.

Limited access to basic services is the other source of vulnerability at the household level. For instance, farmers who have access to credit services are less vulnerable than farmers with no access to credit services. Additionally, farmers who have access to extension on livestock and crop productions are less vulnerable than farmers who do not. In general, using different scenarios of poverty lines affect vulnerability at the household level almost similarly across the different scenarios.

Table 15 Vulnerability by household characteristics and climate extreme events using 2.0 and 1.5 US dollars per day

Description of household characteristics and climate extreme events	2.0 $ US		1.5 $US	
	Mean Vulnerability	Std. Dev.	Mean Vulnerability	Std. Dev.
Droughts occurred during the prior five years,	0.95	0.10	0.90	0.15
Floods occurred during the prior five years,	0.93	0.11	0.88	0.17
Hailstorms occurred during the prior five years,	0.92	0.12	0.86	0.18
Education of household head higher than sample average	0.89	0.13	0.82	0.20
Education of household head lower than sample average	0.94	0.11	0.89	0.16
Small-sized households (< 4 members)	0.93	0.10	0.87	0.19
Medium-sized households (4 < members < 10)	0.92	0.12	0.86	0.18
Large-sized households (members >10)	0.93	0.10	0.88	0.13
Male household head	0.92	0.12	0.85	0.18
Female household head	0.99	0.04	0.97	0.07
Young household head (< 25 years)	0.85	0.13	0.76	0.20
Middle-aged household head (25 < age < 45)	0.92	0.12	0.85	0.19
Old aged household head (age > 45)	0.94	0.10	0.89	0.15
Owning livestock	0.93	0.11	0.86	0.17
Not owning livestock	0.94	0.12	0.87	0.21
Access to extension services	0.88	0.11	0.83	0.17
No access to extension services	0.91	0.12	0.84	0.18
Access to credit services	0.90	0.14	0.84	0.19
No access to credit services	0.93	0.10	0.87	0.16
Small-sized farm (<0.75 hectare)	0.93	0.10	0.87	0.15
Medium-sized farm (0.75 < farm size < 5 hectare)	0.92	0.12	0.86	0.18
Large-sized farm (> 5 hectare)	0.93	0.12	0.88	0.17

For instance, increasing the poverty line from 0.3 US dollar per day to 2 US dollars per day increases the vulnerability of female headed households from 0.23 to 0.99 (Tables 15 and 16) and the interpretation of the other variables also follow the same argument.

Table 16: Vulnerability by household characteristics and climate extreme events using 1.25 and 0.3 US dollars per day

Description of household characteristics and climate extreme events	1.25 $US		0.3 $US	
	Mean Vulnerability	Std. Dev.	Mean Vulnerability	Std. Dev.
Droughts occurred during the prior five years,	0.76	0.25	0.06	0.10
Floods occurred during the prior five years,	0.76	0.26	0.06	0.08
Hailstorms occurred during the prior five years,	0.70	0.28	0.05	0.10
Education of household head higher than sample average	0.66	0.29	0.05	0.10
Education of household head lower than sample average	0.75	0.26	0.08	0.15
Small-sized household (< 4 members)	0.73	0.29	0.07	0.12
Medium-sized households (4 < members < 10)	0.72	0.27	0.07	0.14
Large-sized households (members >10)	0.73	0.19	0.10	0.16
Male household head	0.70	0.27	0.06	0.11
Female household head	0.94	0.13	0.23	0.24
Young household head (< 25 years)	0.60	0.29	0.10	0.12
Middle- aged household head (25 < age < 45)	0.71	0.28	0.08	0.15
Old aged household head (age > 45)	0.75	0.26	0.07	0.13
Owning livestock	0.72	0.27	0.03	0.14
Not owning livestock	0.73	0.31	0.08	0.031
Access to extension services	0.74	0.26	0.05	0.10
No access to extension services	0.76	0.28	0.10	0.17
Access to credit services	0.70	0.25	0.07	0.14
No access to credit services	0.73	0.28	0.09	0.13
Small-sized farm (<0.75 hectare)	0.72	0.24	0.07	0.12
	0.73	0.28	0.07	0.14
Medium-sized farm (0.75 < farm size < 5 hectare)	0.72	0.21	0.04	0.05
Large-sized farm (> 5 hectare)				

4.2. 7 Conclusions and policy implications

Based on household-level survey data from the Nile Basin of Ethiopia, the above analysis adopted vulnerability as an expected poverty approach to analyse the probability of farmers falling below a given consumption (income) level due to climatic shocks (droughts, floods and hailstorms). The logarithm of income is assumed to substitute the logarithm of consumption, as most farmers in Ethiopia consume most of their farm's incomes.

A sensitivity analysis, applied by fixing the minimum daily income at different levels is used to examine the proportion of households vulnerable to climate extremes when the minimum daily income is 2, 1.5, 1.25 or 0.3 USD per day. When the minimum income was fixed at 2 USD per day, the majority of the surveyed farmers fell below the poverty line. In contrast, when the minimum income was fixed at 0.3 USD per day, only 7 percent of the surveyed farmers fell below the vulnerability line. Moreover, farmers living in different agro-ecological settings have different levels of vulnerability under the four scenarios. Additionally, a vulnerability analysis at the household level revealed that households with low level of education, female headed households, old age heads of household, farmers who do not own livestock and do not have access to basic services are vulnerable to extreme climate events.

The analysis shows that farmers' vulnerability is highly sensitive to their minimum income per day requirement (poverty line) and the agro-ecological settings. When the minimum requirement is higher, most people were vulnerable to poverty due to climate extremes, whereas the level of vulnerability was lower when the minimum requirement is lower. Furthermore, farmers living in Kola zones are relatively more vulnerable to extreme climate events than farmers living in the other agro-ecological zones. The results further revel that highly impoverished households who have limited access to basic services and wealth are more vulnerable to extreme climates than households with better access to basic services and wealth.

Notably, these results indicate that increasing a farms income, with special emphasis on farmers in the Kola agro-ecologies, and enabling them to meet the daily minimum requirement will reduce their vulnerability to climate extremes. Thus, policy interventions should focus on strengthening both household- and public-level climate risk management, through mitigation and coping practices aimed at reducing the damages from climate change. The risk-mitigation strategies that should be addressed at the household level should include: those that encourage crop and livestock diversification; the use of drought-tolerant crop varieties and livestock species; the mixing of crop and livestock production; and membership in rotating credit groups. Policies that support coping strategies at the household level should encourage income generation and asset holding with special emphasis on female headed households, both of which will enable consumption smoothening during, and immediately after, harsh climatic events.

Public-level risk mitigation strategies might include: investment in education and basic services; inception of old age insurance; water harvesting; resource conservation and management; irrigation; voluntary resettlement programmes; provision of household and agro-ecological extension packages; inception of productive safety net programs; provision of weather-indexed drought insurance; and the development of well coordinated drought early warning systems. Some helpful public-level coping strategies might be those focusing on the efficient administration of foreign emergency relief aid and effective food-for-work programmes.

4.3 Measuring farmer's vulnerability to climate change across the regional states of Ethiopia

4.3.1 Specification of the vulnerability indicator approach for measuring vulnerability across the regional states

This study analysed the vulnerability of Ethiopian farmers to climate change based on the integrated vulnerability assessment approach using vulnerability indicators. The vulnerability indicators consist of the different socio-economic and biophysical attributes of Ethiopia's seven agriculture-based regional states. The different socio-economic and biophysical indicators of each region collected, were classified into three classes based on the Intergovernmental Panel on Climate Change's (IPCC 2001) definition of vulnerability. The IPCC defines vulnerability to climate change as follows:

> The degree to which a system is susceptible, or unable to cope with adverse effects of climate change, including climate variability and extremes, and 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.

Figure 9 sketches the conceptual framework used for this study based on the IPCC's definition of vulnerability. This figure suggests that Ethiopian farmers are exposed to both gradual climate change (mainly temperature and precipitation) and extreme climate change (mainly droughts and floods). Exposure affects sensitivity, which means that exposure to higher frequencies and intensities of climate risk, highly affects the outcome (e.g. yield, income and health). Exposure is also linked to an adaptive capacity. For instance, a higher adaptive capacity reduces the potential damage from higher exposure. Sensitivity and adaptive capacities are also linked. Given a fixed level of exposure, the adaptive capacity influences the level of sensitivity. In other words, a higher adaptive capacity (socio-economic vulnerability) results in lower sensitivity (biophysical vulnerability) and vice versa. Therefore, a sensitivity and adaptive capacity adds up to total vulnerability.

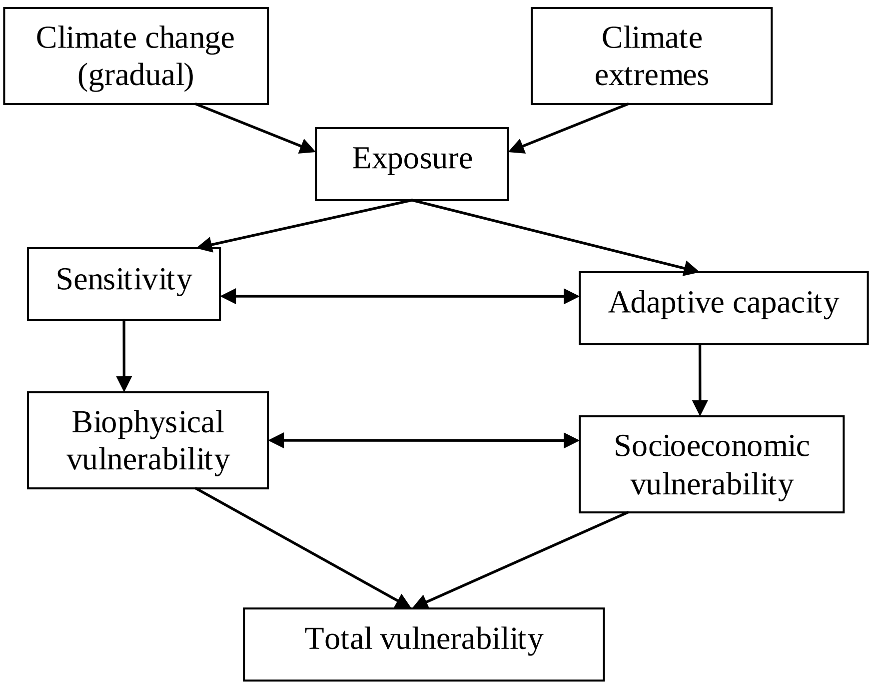

Figure 9: Conceptual framework to vulnerability assessment

As indicated earlier (section 3.3.2), the use of indices is challenged by many ambiguities, some of which are the choices of the: right indicators; directions of relationships with vulnerability; weights attached; and the optimal scale. The choice of indices was undertaken based on a review of the literature and adjusting to the context of Ethiopian agriculture. The direction of the relationship in vulnerability indicators (i.e. their sign) was adopted from the procedure followed by Moss *et al*. (2001), who assigned a negative value to sensitivity and a positive value to adaptive capacity and then calculated the vulnerability resilience indicator. In this study, negative values were attached to both exposure and sensitivity. The main argument for this is that areas that are highly exposed to a damaging climate are more sensitive to damages, assuming a constant adaptive capacity.

Sensitivity could best be measured by a change in income or livelihood attributed only to climatic factors. However, it was not possible to find this type of data. Instead, simple assumptions were made in which those areas with higher frequencies of climate extremes (e.g. droughts and floods) were subjected to higher sensitivity due to loss in yield and thus loss of livelihood, given that the main source of livelihood in rural Ethiopia is agriculture. In addition, exposure could best be represented by both future gradual changes in climate and the forecasted values of the probabilities of extreme events (e.g. droughts and floods). Data on the forecasted probabilities of future climate extremes were not found. Thus, a very simple assumption was made in which areas with higher changes in temperature and precipitation are more exposed. Variables listed under an adaptive capacity were given a positive value. In this study, it is assumed that people with a higher adaptive capacity are less sensitive to damages from climate change, keeping the level of exposure constant. Therefore, vulnerability is calculated as the net effect of adaptive capacity, sensitivity and exposure.

$$\textit{Vulnerability} = (\textit{adaptive capacity}) - (\textit{sensitivity} + \textit{exposure}) \qquad (4.6)$$

In this relationship, higher net value indicates lesser vulnerability and vice versa.

The next step is the attachment of weights to the vulnerability indices. For this step, the method of principal components analysis (PCA) was employed. PCA is frequently used in research that is based on constructing indices for which there are no well-defined weights. The use of asset-based indices for measurements of wealth across different social groups is a good example (Filmer and Pritchett 2001; Langyintuo 2005; Sumarto *et al*. 2006; Vyas and Kumaranayake 2006). The argument here is that as with the asset-based indices for wealth comparison, there are no well-defined weights assigned to the vulnerability indices we chose for this study. Therefore, this study lets a statistical method (PCA) generate the weights.

PCA is a technique for extracting from a set of variables those few orthogonal linear combinations of variables that most successfully capture common information. Intuitively, the first principal component of a set of variables is the linear index of all the variables that captures the largest amount of information common to all the variables. For example, suppose we have a set of *Z*-variables (a^*_{1j} to a^*_{Zj}) that represents the *Z*-variables (attributes) of each region *j*. PCA starts by specifying each variable normalised by its mean and standard deviation. For instance, $a_{1j} = (a^*_{1j} - a^*_1)/s^*_1$, where a^*_1 is the mean of a^*_{1j} across regions and s^*_1 is its standard deviation. The selected variables are expressed as linear combinations of a set of underlying components for each region *j:*

$$a_{1j} = y_{11} W_{1j} + y_{12} W_{2j} + \ldots + y_{1z} W_{zj}$$
$$\ldots \qquad j = 1 \ldots J$$
$$a_{z1j} = y_{z1} W_{1j} + y_{z2} W_{2j} + \ldots + y_{zz} W_{zj}, \qquad (4.7)$$

The *W*'s are the components and the *y*'s are the coefficients on each component for each variable (and do not vary across regions). Because only the left side of each line is observed, the solution to the problem is indeterminate. PCA overcomes this indeterminacy by finding the linear combination of the variables with maximum variance (usually the first principal component W_1j), then finding a second linear combination of the variables orthogonal to the first and with maximal remaining variance, and so on. Technically, the procedure solves the equations $(\mathbf{R} - \lambda\mathbf{I})\mathbf{v}_n = 0$ for λ_n and $\mathbf{v}_n$, where $\mathbf{R}$ is the matrix of correlations between the scaled variables (the *a*'s) and $\mathbf{v}_n$ is the vector of coefficients on the *n*th component for each variable. Solving the equation yields the characteristic roots of $\mathbf{R}$, λ_n (also known as Eigenvalues), and their associated eigenvectors, $\mathbf{v}n$. The final set of estimates is produced by scaling the $\mathbf{v}_n$s so that the sum of their squares sums to the total variance (another restriction imposed to achieve determinacy of the problem).

The scoring factors from the model are recovered by inverting the system implied by equation (4.7). This yields a set of estimates for each of the *Z*-principal components:

$$W_{1j} = b_{11} a_{1j} + b_{12} a_{2j} + \ldots + b_{1z} a_{zj}$$
$$\ldots \qquad j = 1 \ldots J$$
$$Wz_j = b_{z1} a_{1j} + b_{z2} a_{2j} + \ldots + b_{zz} a_{zj}, \qquad (4.8)$$

The *b*'s are the factor scores. Following Filmer and Pritchett (2001), the first principal component, expressed in terms of the original (unnormalised) variables, is an index for each region in Ethiopia based on the following expression:

$$W_{1j} = b_{11}\,(a^*_{1j} - a^*_1)/(s^*_1) + \ldots + b_{1z}\,(a^*_{Zj} - a^*_Z)/(s^*_Z) \qquad (4.9)$$

The final point this study considered in creating the indices was the scale of analysis. Vulnerability analysis ranges from the local or household (Adger 1999) level to the global level (Brooks *et al.* 2005). The choice of scale is dictated by the objectives, methodologies and available data. For this study, the scale of analysis was the regional level, even though the regional level is too aggregated and local variations are often overlooked. In fact, some pockets of the country where drought is so frequent are often masked in regional-scale studies. The most appropriate scale for this type of study is actually the lowest administrative unit, such as a district or even a village within a district. Because this study was limited by the availability of data at these scales, it was undertaken at the regional level.

4.3.2 Data sources

Ethiopia has 11 administrative regions (Figure 10). Data on socio-economic and environmental factors affecting vulnerability were collected for seven of these regions.[3] Socio-economic data include: wealth; income; technology; literacy rate; infrastructure; and institutions. These data were collected from Ethiopia's Central Statistical Agency (CSA 2006). Environmental factors, including irrigation potential and the frequency of droughts and floods, were collected from various sources. Data on irrigation potential was taken from the International Water Management Institute (Awulachew *et al.* 2005). Data on drought and flood frequencies were taken from the International Disaster Database for 1906 to 2006 (Emergency Events Database [EM-DAT] 2006). Predicted changes in climatic variables[4] (i.e. temperature and rainfall) for 2050 were taken from the hydrology component for the GEF Project: Climate Change Impacts on Agriculture in Africa (Strzepek and McCluskey 2006).

4.3.3 Socio-economic and climatic conditions of the selected regional states of Ethiopia

Regions in Ethiopia vary in their socio-economic and environmental characteristics. Appendices 1 to 4 depict the indicators of adaptive capacity, whereas Appendices 5 and 6 depict indicators of sensitivity and exposure across the seven agricultural regions. Farmers

3 No data were available for the Gambella region. Addis Ababa, Dire Dawa, and Harari were excluded, because they are very small in comparison with the other regions, and they are not rural.

4 Data from different metrological stations in different districts were aggregated over each region.

living in Amhara and Oromia are wealthier than those in the other regions in terms of the quality of the houses they own. The percentage of people owning radios is highest in Afar and lowest in Amhara. Livestock ownership is highest in Somali, due to the fact that most farmers in Somali are nomads and make their livelihoods mostly from livestock. Overall, a very small proportion of farmers in Ethiopia have access to nonagricultural income, gifts, and remittance, clearly indicating that agriculture is the main source of livelihood in the rural community. Appendix 1 shows the wealth distribution across the seven regional states.

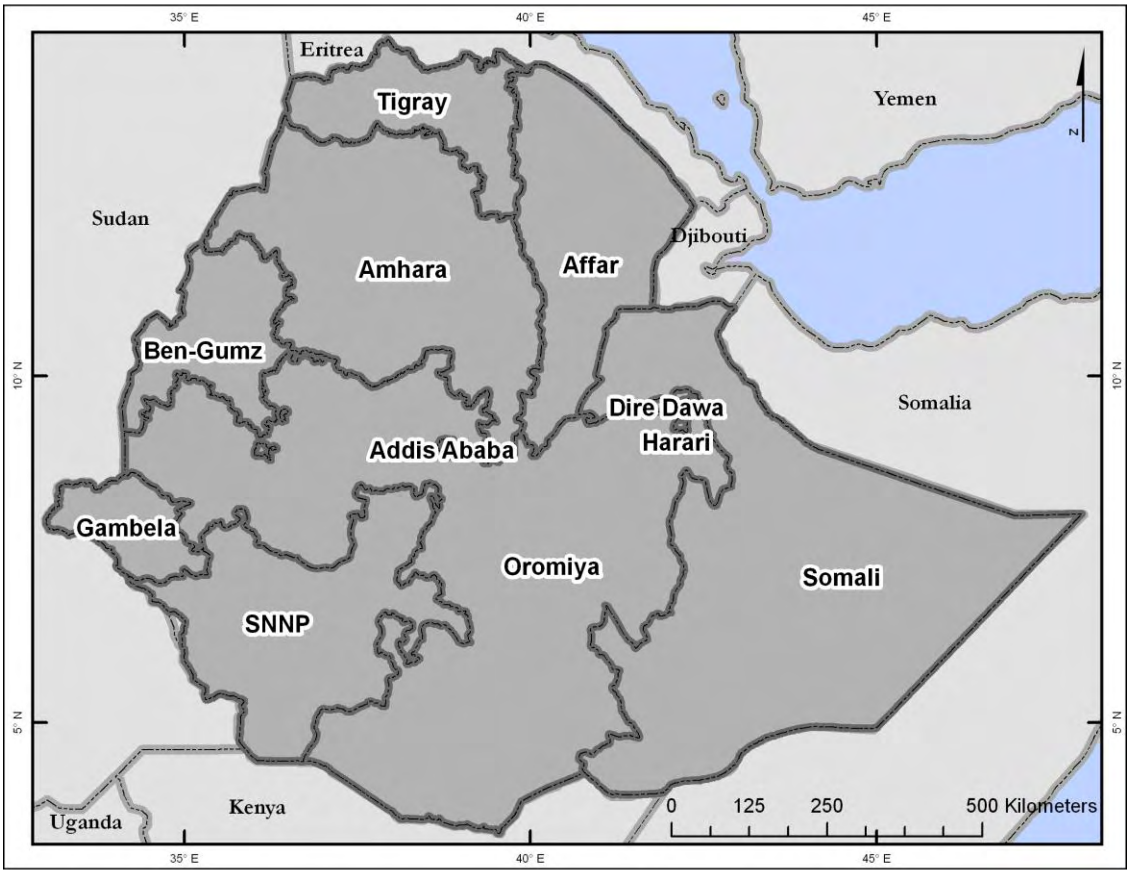

Figure 10: Ethiopia's regional states

SNNP has the highest access to technology, as the percentage of farmers in this region are the highest in terms of proximity to insecticides, pesticides, fertilizer and supplies of improved seeds. Farmers in Somali and Afar have the lowest access to supplies of inputs (Appendix 2).

Afar has the highest proportion of all-weather roads and health services; whereas Somali has the lowest proportion of health services and Amhara has the lowest proportion of all-weather roads. Food market is highest in SNNP and lowest in Somali and Amhara. Primary and secondary schools are relatively equally distributed across the regions, except for Somali, in which they are very low. Telephone services are highest in rural Afar and lowest in Benishangul-Gumuz. Tigray has the highest proportion of microfinance and veterinary services, whereas Somali has the lowest proportion of both microfinance and veterinary services (Appendix 3). Irrigation potential and literacy rates are highest in SNNP and Tigray. Irrigation potential and literacy rates are lowest in Afar and Somali (Appendix 4). In terms of the frequency of droughts and floods, Amhara stands first (even though the figures for Oromia and Somali are closer), whereas Benishangul-Gumuz and Afar experienced a lesser frequency of droughts and floods over the past century (Appendix 5). By 2050, the predicted change in temperature (increment) is highest for Afar and Tigray and lowest for SNPP, whereas the change in precipitation[5] is the highest for Somali and lowest for SNPP (Appendix 6).

4.3.4 Description of model variables

The model variables for this analysis were categorised according to the study's conceptual framework (Figure 9 in section 4.3.1). Adaptive capacity is the ability of a system to adjust to actual or expected climate stresses or to cope with the consequences of those stresses. According to IPCC (2001), the main features determining a community or region's adaptive capacity include: economic wealth; technology; information and skills; infrastructure; institutions; and equity.

For this analysis, adaptive capacity is represented by wealth, technology, availability of infrastructure and institutions, potential for irrigation and literacy rate. Wealth enables communities to absorb and recover from losses more quickly due to insurance, social safety nets and entitlement programmes (Cutter *et al.* 2000). The number of owned livestock, ownership of a radio and quality of residential homes are commonly used as indicators of wealth in rural African communities (Langyintuo 2005; Vyas and Kumaranayake 2006). Proximity to supplies of agricultural inputs is identified as an indicator of technology. For instance, drought-tolerant or early maturing varieties of crops as technology packages usually require access to complementary inputs, such as fertilizers or pesticides. Thus, the supplies of such inputs positively contribute to successful adaptation.

5 Climate prediction studies on precipitation for Ethiopia are inconclusive, with some indicating increases and others decreases in rainfall.

The level of development and availability of institutions and infrastructure play an important role in adaptation to climate change by facilitating access to resources. For instance, all-weather roads allow for the distribution of necessary inputs to farmers, which helps them adapt to climate change. These roads also facilitate economic activity by increasing access to markets. Likewise, health services can assist in the provision of preventive treatments for diseases associated with climatic change, such as malaria. And the availability of microfinance often supports farmers by providing credits for technology packages. Smith and Lenhart (1996) indicated that countries with well-developed social institutions are considered to have a greater adaptive capacity than those with less-effective institutional arrangements. According to O'Brien *et al.* (2004), areas with better infrastructure are expected to have a higher capacity to adapt to climate change. In their analysis of the vulnerability of Indian agriculture to climate charge, for example, O'Brien *et al.* (2004) included India's infrastructure development index, which includes the availability of: transportation; irrigation; banking; communication; education; and health facilities to measure adaptive capacity.

Irrigation potential and literacy rate are other important factors contributing to adaptation to climate change. Irrigation potential was selected because of the assumption that places with more potentially irrigable land are more adaptable to adverse climatic conditions (O'Brien *et al.* 2004). Literacy rate is often included to approximate the level of skills and education of a region. Smith and Lenhart (1996) argued that countries with higher levels of stores of human knowledge are considered to have a greater adaptive capacity than developing nations and those in transition.

'Sensitivity' is the degree to which a system is affected, either adversely or beneficially, by climate change stimuli, whereas 'exposure' is the nature and degree to which a system is exposed to climate variations (IPCC 2001). The agricultural sector's sensitivity to climate change is represented by the frequency of climate extremes. In our study, it is argued that in places with a greater frequency of droughts and floods, the agricultural sector responds negatively (i.e. yield is reduced). Thus, agriculture in areas that are prone to droughts and floods is more sensitive in terms of yield reduction.

'Exposure' is represented by the predicted change in temperature and rainfall by 2050. This figure provides the level of climate change to which regions are exposed. It is generally agreed that increasing temperature and decreasing precipitation are both damaging to the already hot and water-scarce African agriculture. Thus, regions with increasing temperature and decreasing rainfall were identified as regions more exposed to climate change. Table 17 gives the indicators and the hypothesised direction of relationship with vulnerability.

Table 17: Vulnerability indicators, units of measurement and expected direction with respect to vulnerability

Determinants of Vulnerability	**Vulnerability Indicators**	**Description of each Indicator selected for analysis**	**Unit of Measurement**	**Hypothesised functional relationship between Indicator and Vulnerability**
Adaptive capacity	Wealth	Livestock ownership Ownership of radio Quality of residential home Non-agricultural income Gift and remittance	Percentage of total population who own or have access to	The higher the percentage of total population with asset ownership, and access to these income sources the lesser the vulnerability.
	Technology	Insecticide and pesticide supply Fertilizer supply Improved seeds supply	Percentage of total population within 1–4 kilometers of supply sources	The higher the percentage of total population of the region within 1–4 kilometers, the lesser the vulnerability.
	Infrastructures and institutions	All-weather roads Health services Telephone services Primary and secondary schools Veterinary services Food market Microfinance	Percentage of total population within 1–4 kilometers of these infrastructures and institutions	The higher the percentage of total population of the region within 1–4 kilometers, the lesser the vulnerability.
	Irrigation potential	Irrigation potential	Percentage of potential irrigable land (irrigable land divided by total area)	The higher the irrigation potential, the lesser the vulnerability.
	Literacy rate	Literacy rate age 10 years and older	Percentage of total population	The higher the literacy rate, the lesser the vulnerability.
Sensitivity	Extreme climate	Frequency of droughts and floods	Number of occurrences (count the occurrences of droughts and floods in different parts of the region)	The higher the frequency, the more the vulnerability.
Exposure	Change in climate	Change in temperature Change in precipitation	Change (delta T) in degrees from base value (2000) Percentage change from base value (2000)	Increasing temperature and decreasing precipitation increase vulnerability.

4.3.5 Results and discussion

For this analysis, PCA was run on the indicators listed in Table 17. The PCA of the data set on vulnerability indicators revealed three components with eigenvalues greater than 1. These three components explain 95 percent of the total variation in the data set. The first principal component explained most of the variation (56 percent), and the second principal component explained 25 percent, and the third explained the least (14 percent). Based on earlier arguments for the use of PCA in constructing indices, the first principal component, which explained the majority of the variation in the data set, was taken. As can be observed from the factor scores, the first PCA (our vulnerability index, in this case) was positively associated with the majority of the indicators identified under adaptive capacity and negatively associated with all the indicators categorised under exposure and sensitivity (Table 18).

Thus, for the construction of the vulnerability indices, indicators of adaptive capacity, which are positively associated with the first PCA and all the indicators of sensitivity and exposure as they are negatively associated with our PCA (remaining with a total of 15 indices), were selected. Higher values of the vulnerability index show less vulnerability and vice versa, as we are dealing with the fact that adaptive capacity is positively loading. The exposure and sensitivity indices are negatively loading to our PCA.

Factor scores from the first principal component were employed to construct indices for each region. For instance, the vulnerability index for Afar is calculated as follows:

$$\begin{bmatrix} (0.1096 * -0.76856494) + (0.0375 * 1.094139) + (0.29 * -1.08114) + \\ (0.2873 * -1.40065) + 0.2789 * -1.08821) + (0.2597 * 1.956076) + \\ (0.1737 * -0.05282) + (0.2958 * 0.215667) + (0.2107 * -1.09422) + \\ (0.2586 * -0.02715) + (0.2595 * -1.04492) + (0.2799 * -1.1312) \end{bmatrix} - \begin{bmatrix} (0.1852 * -1.12272) + \\ (0.0508 * 1.141059) + \\ (0.272 * -0.06116) \end{bmatrix} = -1.16 \qquad (5)$$

$$(weighted \quad indices \quad of \quad adaptive \quad capcity) \; - \; (weighted \quad indices \quad of \; \exp osure + sensetivity)$$

Table 18: Factor scores of the first principal component

Vulnerability indicators	Factor scores
Ownership of livestock	–0.2951
Ownership of radio	0.0375
Quality of house	0.1096
Non-gricultural income	–0.1264
Gifts and remittances	–0.2863
Insecticide and pesticide supply	0.29
Fertilizer supply	0.2873
Improved seeds supply	0.2789
All-weather roads	–0.0637
Health services	0.2597
Telephone services	–0.0140
Primary and secondary schools	0.2958
Veterinary services	0.2586
Food market	0.1737
Microfinance	0.2107
Irrigation potential	0.2595
Literacy rate	0.2799
Frequency of climate extremes	–0.1852
Change in temperature	–0.0508
Change in precipitation	–0.2720
Eigenvalue	11.23
Proportion of variance	56.16
Cumulative proportion	56.16

The calculations for the rest of the regions followed the same procedure. Appendix 7 presents the normalised values for each variable by their means and standard deviations for all regions. Figure 11 shows the vulnerability index for each region.

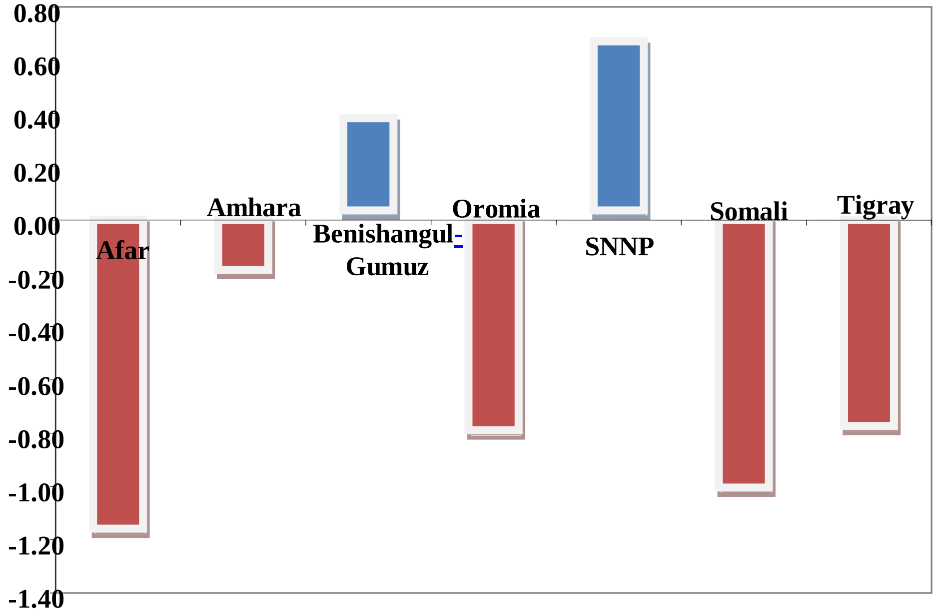

Figure 11: Vulnerability indices of the seven regional states of Ethiopia

Figure 11 shows that the net effect of adaptation, exposure and sensitivity is positive for SNNP and Benishangul-Gumuz, but negative for Afar, Amhara, Oromia Somali, and Tigray. This indicates that SNNP and Benishangul-Gumuz are relatively not vulnerable, whereas Afar, Amhara, Oromia and Somali are vulnerable. The lesser vulnerability of SNNP is associated with its relatively higher access to technology and food market, its highest irrigation potential and its literacy rate. Afar, Somali, Oromia and Tigray are among the highly vulnerable regions. The vulnerability of Afar and Somali is mainly associated with lower levels of regional development. Despite the fact that these regions are less populated than the other regions, the percentage of people with access to institutions and infrastructure remains very low due to the lowest level of regional development.

The vulnerability of Oromia is associated with a high frequency of droughts and floods and lower access to technology, institutions and infrastructure. Similarly, the vulnerability of Tigray is attributed to lower access to technology, health services, food markets and telephone services and the high frequency of droughts and floods. Unlike Afar and Somali, the lower access to technology, institutions, and infrastructure in Tigray and Oromia is due to their high population in proportion to what is available.

4.3.6 Conclusions and policy recommendations

This chapter analysed the vulnerability of Ethiopian farmers to climate change by creating vulnerability indices and comparing these indices across regions. Seven of Ethiopia's 11 regional states were considered for this study. The vulnerability analysis followed the IPCC (2001) definition of vulnerability, which explains it as a function of adaptive capacity, sensitivity and exposure.

The socio-economic and environmental factors of each region were included in developing the vulnerability indices. Thus, the integrated vulnerability assessment approaches were adopted to combine these biophysical and socio-economic indicators. The socio-economic factors include wealth, literacy rate, technology, institutions and infrastructure. The biophysical factors include irrigation potential, frequency of climate extremes and future changes in temperature and rainfall. These factors were again divided into three categories to reflect adaptive capacity, sensitivity and exposure. Positive values were attached to adaptive capacity and negative values to sensitivity and exposure. The method of principal component analysis was employed to give weights to the different factors affecting vulnerability.

Vulnerability was calculated as the net effect of sensitivity and exposure on adaptive capacity. Results indicate that Afar, Somali, Oromia and Tigray are relatively more vulnerable to climate change. The vulnerability of Afar and Somali is attributed to their low level of regional development. The vulnerability of Tigray and Oromia is attributed to higher frequencies of droughts and floods and lower access to technology, institutions and infrastructure. Unlike Afar and Somali, the lower access to technology, institutions, and infrastructure in Tigray and Oromia is due to their high population in proportion to what is available

The scale of analysis for this study is at the regional level, which is highly aggregated. Each region included in this study covers a very wide area of land characterised by different biophysical and socio-economic attributes. The variations within each region should be considered in order to target areas that are highly vulnerable and to recommend appropriate interventions. Although the results of this study indicate the general features of each included region, future research should focus on local levels, especially district or village levels, where actual dynamics of vulnerability to climate change take place.

Based on the analysis, a few general policy options for decreasing the vulnerability of Ethiopian farmers to climate change can be presented. In general, vulnerability to climate change in Ethiopia is highly related to poverty (loss of coping or adaptive capacity) in most of the regions that were indicated as vulnerable. Integrated rural development schemes aimed at alleviating poverty can play a double role in reducing poverty and increasing adaptive capacity to climate change. Special emphasis on the relatively less-developed regions of the country (i.e. Afar and Somali), as well as the relatively more populated regions (e.g., Oromia and Tigray), in terms of investment in technology, institutions, and infrastructure can also play a significant role.

Moreover, early warning of extreme climatic events, such as droughts, can alert farmers to sell their livestock and buy food and other items. Without this warning, such events could shrink or kill livestock that would have been used as insurance for farmers. In addition, investment in irrigation in places with high potential for irrigation (e.g. SNNP) can increase the country's food supply. This supply could then be stored and sold out during droughts instead of depending on food aid from other nations. Strengthening the ongoing micro-level adaptation methods of governmental and non-governmental organisations, such as water harvesting and other natural resource conservation programmes, can also boost the adaptive capacities of farmers.

4.4 Summary

This chapter described the vulnerability of Ethiopian farmers at household and regional levels. The household level vulnerability analysis was based on data obtained from a household survey of farmers during the 2004/2005 production year in the Nile Basin of Ethiopia. The analysis adopted the vulnerability to expected poverty approach which is based on estimating the probability that a given shock or set of shocks moves consumption by households below a given minimum level (such as consumption poverty line) or forces the consumption level to stay below the given minimum requirement if it is already below this level. Results indicated that vulnerability is highly sensitive to the amount of minimum requirement (poverty line) that survives farmers per day and agro-ecological settings. Results further indicated that vulnerability varies across households with different socio-economic characteristics. Based on results, different policy options were also presented.

The regional level study analysed the vulnerability of Ethiopian farmers to climate change based on the integrated vulnerability assessment approach using vulnerability indicators. The vulnerability indicators consist of the different socio-economic and biophysical attributes of Ethiopia's seven agriculture-based regional states. The different socio-economic and biophysical indicators of each region collected from different sources have been classified into three classes based on the Intergovernmental Panel on Climate Change's (IPCC 2001) definition of vulnerability, which consists of adaptive capacity, sensitivity and exposure. The results indicated that different regional states of the country are not equally vulnerable to the negative impacts of change and urged the need for policy interventions accordingly.

CHAPTER 5

PERCEPTIONS AND DETERMINANTS OF FARMERS' ADAPTATION CHOICES TO CLIMATE CHANGE IN THE NILE BASIN OF ETHIOPIA

5.1 Introduction

This chapter analyses adaptation measures used by farmers, the determinants of adaptation and factors influencing the perceptions of climate change in the Nile Basin of Ethiopia. The chapter begins with a discussion on the perceptions of climate change and adaptation strategies in the Nile Basin of Ethiopia. The second section discusses the empirical model and model variables. Results and discussions are presented in section three. Section four gives the conclusions and policy implications and section five provides a summary of the chapter.

5.2 Perceptions of climate change and adaptation strategies of farmers in the Nile Basin of Ethiopia

Based on cross-sectional household survey data collected from 1000 households during the 2004/2005 production season in the Nile Basin of Ethiopia as described in section (4.2.3), this section briefly summarises farmers' perceptions of climate change and the strategies they consider appropriate to these changes. The surveyed farm households were asked questions about their observations in the patterns of temperature and rainfall over the past 20 years. The results indicate that 50.6% of the surveyed farmers have observed increasing temperature over the past 20 years whereas 53% of them have observed a decrease in rainfall over the past 20 years (Table 19). Additionally, these farmers who claimed to have observed changes in climate over the past 20 years were subsequently asked if they have responded through adaptations to counteract the impact of the climate change. Accordingly, those who responded that they have adapted to climate change indicate different adaptation strategies which include: planting trees; soil conservation; the use of different crop varieties; changing planting dates; and irrigation (Table 20). These adaptation measures mentioned by Ethiopian farmers are similar to the other findings in the climate change adaptation literature (Bradshaw *et al* 2004; Kurukulasuriya and

Mendelsohn 2008a; Maddison 2006; Hassan and Nhemachena 2007; Hassan and Nhemachena, 2008).

Table 19: Farmers' perception of long-term temperature and precipitation changes

Variable	Percentage of respondents
(a) Temperature	
An increase in Temperature	50.60
A decrease in Temperature	1.90
Temperature stayed the same	14.40
(b) Precipitation	
An increase in Precipitation	10.40
A decrease in Precipitation	53.00
Precipitation stayed the same	12.00
Number of respondents	**995**

Table 20: Farmers' adaptation strategies

Variable	Percentage of respondents
No adaptation	42.00
Planting trees	21.00
Soil conservation	15.00
Different crop varieties	13.00
Early and late planting	5.00
Irrigation	4.00
Total number of respondents	**830**

Moreover, farmers who did not adapt have given many reasons for their failures to adapt which include: lack of information; lack of money; shortage of labour; shortage of land; and poor potential for irrigation (Figure 12).

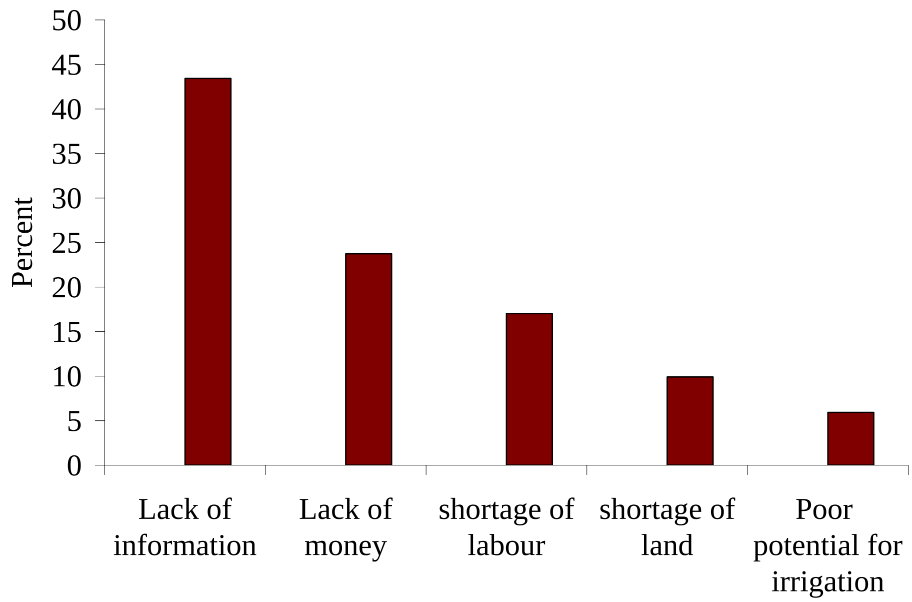

Figure 12: Barriers to adaptation

5.3 The empirical model and model variables

5.3.1 Empirical Model

Adaptation to climate change is a two-stage process involving perception and adaptation stages. The first stage is whether the respondent perceived there was a change in climate or not, and the second stage is whether the respondent adapted to the climate change, conditional to the fact that he or she had perceived there was a climate change in the first stage. Because the second stage of adaptation is a sub-sample of the first stage, it is likely that the second stage sub-sample is non-random and different from those who did not perceive climate change creating a sample selection bias. Therefore, this study used Heckman's well-known maximum likelihood two-step procedure (Heckman 1976) to correct this selectivity bias. The Heckman's two-step procedure has advantages over the other models such as the multinomial logit and multinomial probit models as these models are not suitable for analysing the two- step procedure of adaptation. Heckman's sample selection model assumes that there exists an underlying relationship which consists of:

The latent equation given by:

$$y_j^* = x_j\beta + u_{1j} \tag{5.1}$$

Such that we observe only the binary outcome given by the probit model as**:**

$$y_j^{probit} = (y_j^* > 0) \tag{5.2}$$

The dependent variable is observed only if the observation *j* is observed in the selection equation:

$$y_j^{select} = (z_j\delta + u_{2j} > 0) \tag{5.3}$$

$$u_1 \sim N(0, 1)$$
$$u_2 \sim N(0, 1)$$
$$corr\,(u_1, u_2) = \rho$$

Where *x* is a *k*- vector of explanatory variables which include different factors hypothesised to affect adaptation and *z* is an *m* vector of explanatory variables which include different factors hypothesised to affect perception; u_1 and u_2 are error terms. The first stage of the Heckman's sample selection model is the perceptions of changes in climate and this is the selection model (Equation 5.3). The second stage, which is the outcome model (Equation 5.1), is whether the farmer adapted to climate change, conditional on the first stage that she or he perceived a change in climate.

When $\rho \neq 0$, the standard probit techniques applied to equation (5.1) yield biased results. Thus, the Heckman probit provides consistent, asymptotically efficient estimates for all parameters in such models (Van de Ven and Van Praag 1981). Hence, the Heckman probit selection model is employed to analyse the perception and adaptation to climate change in the Nile Basin of Ethiopia.

5.3.2 Model Variables

5.3.2.1 Dependent and explanatory variables for the outcome equation

The dependent variable for the outcome equation is whether a farmer has adapted or not to climate change. This means that whether a farmer has adopted any of the adaptation methods listed in table 20. The explanatory variables are chosen based on climate change adaptation literature and available data. These variables include: education of the head of the household; the size of the household; the head of the household's gender; non-farm income; livestock ownership; extension on crop and livestock production; access to credit; farm size; distance to input and output markets; temperature and precipitation; as well (Table 21). Moreover, hypotheses on how the explanatory variables influence adaptation to climate change are presented below.

Higher level of education is believed to be associated with access to information on improved technologies and higher productivity (Norris and Batie 1987). Evidence from various sources indicates that there is a positive relationship between the education level of the head of the household and the adoption of improved technologies (Igoden *et al*. 1990; Lin 1991) and adaptation to climate change (Maddison 2006). Therefore, farmers with higher levels of education are more likely to better adapt to climate change.

The influences on the size of a household on the use of adaptation methods can be seen from two angles. The first assumption is that households with large families may be forced to divert part of the labour force to off-farm activities in an attempt to earn income in order to ease the consumption pressure imposed by a large family (Yirga 2007). The other assumption is that a large family is normally associated with a higher labour endowment, which would enable a household to accomplish various agricultural tasks. For instance, Croppenstedt *et al.* (2003) argue that households with a larger pool of labour are more likely to adopt agricultural technology and use it more intensively, because they have fewer labour shortages at peak times. Here it is expected that households with large families are more likely to adapt to climate change.

Male-headed households are more likely to get information about new technologies and undertake risky businesses than female-headed households (Asfaw and Admassie 2004). Moreover, Tenge, de Graffe and Heller (2004) argue that having a female as head of the household may have negative effects on the adoption of soil and water conservation measures, because women may have limited access to information, land and other resources due to traditional social barriers. A study by Hassan and Nhemachena (2007) finds contrary results, arguing that female-headed households are more likely to take up climate change adaptation methods. The authors conclude that women are more likely to adapt, because they are responsible for much of the agricultural work in the region and therefore have greater experience and access to information on various management and farming practices. Thus, the adoptions of new technologies or adaptation methods appear to be rather context specific.

Non-farm income and livestock ownership represent wealth. It is regularly hypothesised that the adoption of agricultural technologies requires sufficient financial well-being (Knowler and Bradshaw 2007). Other studies that investigate the impact of income on adoption found a positive correlation (Franzel 1999). Farmers with a higher income may be less averse to risk and have more access to information, a lower discount rate and a longer-term planning horizon (CIMMYT 1993). Livestock plays a very important role by serving as a store of value and by providing traction (especially oxen) and manure required for soil fertility maintenance (Yirga 2007). Thus for this study, farm and non-farm income and livestock ownership are hypothesised to increase adaptation to climate change.

Extension on crop and livestock production represents access to the information required to make the decision to adapt to climate change. Various studies in developing countries, including Ethiopia, report a strong positive relationship between access to information and the adoption behaviour of farmers (Yirga 2007). Studies on climate change adaptation decisions in Africa reveal that access to information through extension increases the likelihood of adapting to climate change (Maddison 2006; Hassan and Nhemachena 2007). Thus, this study also hypothesises that access to extension on crop and livestock production increases probability of adapting to climate change.

Availability of credit eases the cash constraints and allows farmers to buy purchased inputs such as fertilizer, improved crop varieties and irrigation facilities. Research on the adoption of agricultural technologies indicates that there is a positive relationship between the level of adoption and the availability of credit (Yirga 2007; Pattanayak *et al.* 2003). Likewise, this study also hypothesises that there is a positive relationship between availability of credit and adaptation.

Studies on the adoption of agricultural technologies indicate that the size of farm has both negative and positive effects on adoption, showing that the effect of farm size on technology adoption is inconclusive (Bradshaw *et al.* 2004). However, because the size of farms is associated with greater wealth, it is hypothesised that it can increase adaptation to climate change.

It is hypothesised that as distance to output and input markets increases, the adaptation to climate change decreases. The proximity to markets is an important determinant of adaptation, presumably because the market serves as a means of exchanging information with other farmers (Maddison 2006).

Detailed analysis of the relationships between climatic variables such as temperature and rainfall and choice of adaptation methods requires time series data on how farmers have behaved over time in response to changing climatic conditions. As this type of data is not available for this study, it is assumed that cross-sectional variations can proxy temporal variations. Thus, the analysis hypothesises that including controls for variations in temperature and rainfall across farm households over the 2004/2005 survey period affects adaptation to climate change.

5.3.2.2 Dependent and explanatory variables for the selection equation

The dependent variable for the selection equation is whether a farmer has perceived or not perceived a change in climate. The explanatory variables for the selection equation include different socio-demographic and environmental factors based on literature on factors affecting the awareness of farmers to climate change or risk perceptions. It is hypothesised that: the age and education of the head of the household; the information on climate; farmer-to-farmer extension; number of relatives in the *Got* (village); farm and non-farm incomes; and agro-ecological settings influence the farmers' awareness to climate change (Table 21).

The head of the household's age represents experience in farming. Studies indicate that experienced farmers have a higher probability of perceiving climate change as they are exposed to past and present climatic conditions over the longer horizon of their life span (Maddison 2006; Ishaya and Abaje 2008). Thus, this study hypothesises that older and more experienced farmers have a higher likelihood of perceiving climate change. Education of the head of household, as discussed with the case of factors affecting adaptation, is also hypothesised to positively affect awareness of climate change. Access to information on climate change through extension agents or other sources creates awareness and favourable conditions for the adoption of farming practices that are suitable under climate change (Maddison 2006). Thus, it is hypothesised that farmers' contact with extension agents or any other sources, which provide information on climate change, increases the awareness of farmers.

A higher income positively affects public perception of climate change (Semenza *et al.* 2008). By the same token, it is hypothesised that higher farm and non-farm incomes positively influence farmers' perception of climate change. Farmer-to-farmer extension and the number of relatives in the *Got* (village) represent social capital. In technology adoption studies, social capital plays a significant role in information exchange (Isham 2002). Hence, it is hypothesised that social capital is associated with the perception of climate change.

Table 21: Description of model variables for the Heckman probit selection model

Outcome equation			**Selection Equation**		
Dependent variable			Dependent variable		
Description	Farmers adapted (%)	Farmers not adapted (%)	Description	Farmers perceived change (%)	Farmers who not perceived change (%)
Adaptation to climate change (Dummy: takes the value of one if adapted and zero otherwise)	58	42	Perception of climate change (Dummy: takes the value of one if perceived and zero otherwise)	83	17
Independent variables			Independent variables		
Description	Mean	Standard deviation	Description	Mean	Standard deviation
Education of household head in years	1.70	2.78	Education of household head in years	1.70	2.78
Size of household in numbers	6.15	2.22	Age of Household head in years	44.29	12.62
Gender (Dummy: takes the value of 1 if male and 0 otherwise)	0.89	0.31	Farm income in Ethiopian currency	4374.76	7018.64
Non-farm income in Ethiopian currency	218.26	791.00	Non-farm income in Ethiopian currency	218.26	791.00
Livestock ownership (Dummy: takes the value of 1 if owned and 0 otherwise)	0.95	0.22	Information on climate (Dummy: takes the value of 1 if there is and 0 otherwise)	0.37	0.50
Extension on crop and livestock (Dummy : takes the value of 1 if visited & 0 otherwise)	0.55	0.50	Farmer-to-farmer extension (Dummy: takes the value of one if there is & 0 otherwise)	0.48	0.50
Credit (Dummy: takes the values of 1 if there is access and 0 otherwise)	0.22	0.41	Number of relatives in *Got* (village)	13.37	19.44
Farm size in hectares	2.02	1.18	Local Agro-ecology Kola (lowland) (Dummy: takes the values of 1 if Kola and 0 otherwise)	0.25	0.43
Distance to output market in kilometers	5.70	4.14	Local Agro-ecology Dega (highland) (Dummy: takes the value of 1 if Dega & 0 otherwise)	0.25	0.43
Distance to input market in kilometers	5.61	4.22	Local Agro-ecology Weynadega (midland) (Dummy: takes the value of 1 if Weynadega & 0 otherwise)	0.50	0.50
Temperature in degree centigrade (annual average over the 2004-2005 survey period)	18.61	1.34			
Precipitation in millimeters (annual average over the 2004-2005 survey period)	115.64	35.57			

The agro-ecological setting of farmers influences the perception of farmers to climate change. A study by Diggs (1991) revealed that farmers living in drier areas frequented by droughts are more likely to describe the climate change to be warmer and drier than farmers living in a relatively wetter area with a less frequent occurrence of drought. According to Diggs (1991), this is associated with the cognitive heuristics used by farmers in the formation of climate change perceptions which is based on the frequency of drought in drier areas. In Ethiopia, lowland areas are drier with a higher drought frequency than other places (Belay *et al.* 2005). Thus, it is hypothesised that farmers living in lowland areas are more likely to perceive climate change as compared to midland and highland areas.

5.4 Model results and discussion

The Heckman probit model was run and tested for its appropriateness over the standard probit model. The results indicated the presence of sample selection problems (dependence of the error terms from the outcome and selection models) justifying the use of the Heckman probit model with rho significantly different from zero (Wald χ^2 = 10.84, with p = 0.001). Moreover, the likelihood function of the Heckman probit model was significant (Wald χ^2 = 86.45, with $p < 0.0000$) showing strong explanatory power of the model. Additionally, results show that most of the explanatory variables and their marginal values are statistically significant at 10% or lower and the signs on most variables are as expected, except for a few (Table 22). The calculated marginal effects measure the expected changes in the probability of both perception of climate change and adaptation with respect to a unit change in an independent variable.

The results from the selection model, which analyses the factors affecting the perception of climate change, indicate that: the age of the head of the household; farm income; information on climate change; farmer-to-farmer extension; the number of relatives in a *Got* (village); and the agro-ecological settings affect the perception of climate change. The higher likelihood of perceiving climate change with the increased age of the head of the household is associated with experience, which lets farmers observe changes overtime and compare it with current climatic conditions. Information on climate change through extension or other public sources, farmer-to-farmer extension and number of relatives in the *Got* increase the likelihood of perception as they play an important role in the availability and flow of information.

Unlike prior expectations, farmers living in Dega (highlands) perceived more change in climate than farmers in Kola (lowlands) when compared with Weynadega (midlands). This could either be associated with the recent drought (in 2002), with the peoples' need for more rainfall or could be linked to various environmental changes, which cause reduced water availability (Meze-Hausken 2004). It might also be linked to various problems like soil erosion, which reduces yield, or population pressure, which increases the demand for food.

The results from the outcome model, which analyses the factors affecting adaptation, indicated that most of the explanatory variables affected the probability of adaptation as expected, except farm size. Variables that positively and significantly influenced adaptation to climate change include: education of the head of the household; household size; the gender of the head of the household being male; livestock ownership; extension on crop and livestock production; availability of credit; and temperature. The fact that increasing the number in a household increases the likelihood of adaptation is in line with the argument which assumes that a large family is normally associated with a higher labour endowment, which would enable a household to accomplish various agricultural tasks especially during peak seasons (Croppenstedt *et al.* 2003). A higher probability for male-headed households to better adapt to climate change also agrees with the fact that male-headed households often have a higher probability of adopting agricultural technologies (Buyinza and Wambede 2008). The fact that adaptation to climate change increases with increasing temperature agrees with the expectation that increasing temperature is damaging to African agriculture and farmers respond to this through the adoption of different adaptation methods (Kurukulasuriya and Mendelsohn 2008a).

Table 22: Results of the Heckman probit selection model

Explanatory variables	Adaptation model				Selection model			
	Regression		Marginal impacts		Regression		Marginal values	
	Coefficients	P-level	Coefficients	P-level	Coefficients	P- level	Coefficients	P-level
Education	0.061**	0.017	0.019**	0.017	0.021	0.393	0.005	0.388
Household size	0.058*	0.053	0.018*	0.051				
Gender of household head	0.580***	0.010	0.177**	0.012				
Age of household head					0.018***	0.000	0.004***	0.000
Farm income					5.66E-05***	0.000	0.000013***	0.000
Non-farm income	0.000149	0.143	4.55E-05	0.144	-1.1E-05	0.911	-2.54E-06	0.911
Livestock ownership	1.012***	0.003	0.309***	0.004				
Extension on crop and livestock	1.024***	0.000	0.303***	0.000				
Information on climate change					0.372**	0.014	0.080***	0.009
Farmer-to-farmer extension					0.707***	0.000	0.155***	0.000
Credit availability	0.479***	0.003	0.131***	0.001				
Number of relatives in *Got*					0.011**	0.038	0.003**	0.035
Farm size in hectares	-0.140**	0.011	-0.043**	0.013				
Distance to output market	-0.053	0.310	-0.016	0.310				
Distance to input market	0.075	0.143	0.023	0.141				
Local Agro-ecology (Kola)					0.047	0.761	0.011	0.757
Local Agro-ecology (Dega)					0.849***	0.000	0.155***	0.000
Temperature	0.178***	0.000	0.055***	0.000				
Precipitation	-0.012***	0.000	-0.004***	0.000				
Constant	-3.670	0.000			0.821***	0.001		
Total observations	608							
Censored	126							
Uncensored	482							
Wald Chi-square (Zero slopes)	86.45***							
Wald Chi-square	10.84 ***							

***, **, * = Significant at 1%, 5% and 10% probability level, respectively

Farm size and annual average precipitation are negatively related to adaptation. The probable reason for the negative relationship between adaptation and farm size could be due to the fact that adaptation is plot specific. This means that it is not the size of the farm, but the specific characteristics of the farm that dictates the need for a specific adaptation method to climate change. Thus future research, which accounts for farm characteristics, could reveal more information about factors dictating adaptation to climate change at farm or plot level. Moreover, the probable reason for the negative relationship between average annual precipitation and adaptation could be due to the fact that increasing precipitation relaxes the constraint imposed by increasing temperature on crop growth.

5. 5 Conclusion policy implications

Farmers should be able to adapt in order to reduce the negative impact of climate change. Adaptation to climate change is a two-step process which requires that farmers perceive climate change in the first step and respond to changes in the second step through adaptation. Different socio-economic and environmental factors affect the ability to perceive and adapt to climate change.

This study analysed the factors affecting the perceptions of and adaptation to climate change based on a household survey of a total of 1000 mixed crop and livestock farmers during the 2004/2005 production year in the Nile Basin of Ethiopia. Farmers were asked if they have perceived any change in the patterns of rainfall and temperature over the past 20 years. The majority of farmers indicated that they have observed an increase in temperature and a decrease in rainfall. Farmers who claimed to have observed climate change were further asked if they have adapted. Accordingly, some of those who claimed to have observed climate change indicated that they have adapted by adopting different methods. The remaining farmers who have observed and did not adapt to climate change indicated lack of information on the types of adaptation methods and lack of money to be able to adapt as the major barriers to adaptation.

The Heckman probit selection model was employed to analyse the two-stage process of adaptation in the Nile basin of Ethiopia. Results from the first stage regression indicate that: the age of the head of the household; farm income; information on climate change; farmer-to-farmer extension; the number of relatives in a *Got* (village); and the agro-ecological settings that affect the perception of climate change. Additionally, the results from the second stage regression indicate that: the head of the household's education; the size of the household; the gender of the head of the household being male; livestock ownership; the extension on crop and livestock production; the availability of credit; and temperature affect adaptation to climate change.

Most of the above factors identified as affecting the perception of and adaptation to climate change in the Nile Basin of Ethiopia are directly related to the development of institutions and infrastructure. This is in line with the current Ethiopian government policy on poverty reduction and accelerated development through investment on education to enhance: human capacity; infrastructure such as roads and telecommunications; and institutions such as credit facilities both in urban and rural areas (MoFED 2007). Although current efforts by the government assists in enhancing adaptive capacity, more needs to be done in terms of effective adaptation to climate change to protect the already weak agricultural sector. Therefore, a future policy should focus on awareness creation on climate change through different sources such as mass media and extension; facilitating the availability of credit especially to adaptation technologies; enhancing research on use of new crop varieties and livestock species that are more suited to drier conditions and different agro-ecological settings and investment on irrigation. Moreover, encouraging income generating schemes, informal social net-works and importing adaptive technologies from other countries with similar socio-economic and environmental settings enhance the adaptive capacity of Ethiopian farmers.

5 .6 Summary

This chapter identified the main methods used by farmers to adapt to climate change and the barriers to adapt to climate change. The main adaptation methods identified include: use of different crop varieties; tree planting; soil conservation; early and late planting; and irrigation. Farmers who perceived climate change, but failed to adapt, indicated that lack of information on the types of adaptation methods and lack of money to be able to adapt are the major barriers to adaptation.

The chapter also discussed the factors affecting the perception of climate change and adaptation. The Heckman probit model was adopted to analyse the two-step process of adaptation to climate change, which initially requires farmer's perception that climate is changing and then responding to changes through adaptation. The analysis of perception of farmers to climate change revealed that: the head of the household's age; wealth; information on climate change; and social capital and agro-ecological settings have significant impact on the perception of farmers to climate change. Moreover, the analysis adaptation revealed that the head of the household's education; the size of the household; the gender of the head of the household being male; livestock ownership; the extension on crop and livestock production; the availability of credit; and temperature affect adaptation to climate change. Additionally, this chapter recommended different policy options based on the results of the study.

CHAPTER 6

SUMMARY, CONCLUSIONS, IMPLICATIONS AND LIMITATIONS OF THE STUDY

6.1 Conclusions and implications for policy

Ethiopia is one of the poorest countries in the world with the majority of its population living under the poverty line. One of the major reasons why poverty is so high in the country is the economy's dependence on agriculture, which has failed to meet the growing demands for food for the population and left the nation dependent on food aid. Although many factors contribute to the poor performance of the agricultural sector, poor climatic conditions, especially recurring droughts, are the main reasons. Moreover, the past trends of climate change and climate variability, which hinder agricultural production, are expected to sustain in the future. This indicates that the country's agriculture must cope with further warming, low rainfall patterns and frequent climatic extremes (such as droughts and floods).

Studies have been undertaken to measure the impact of climate change on Ethiopian agriculture and water resources. Studies on agriculture have analysed monetary or yield impacts of climate change and suggested adaptation measures, but did not analyse factors affecting the choice of the suggested adaptation methods. This presents an important limitation, because a deep understanding of how farmers respond to climate change or their choice of adaptation methods is influenced by a host of socio-economic and environmental factors. Other studies have attempted to analyse the impact of climate change and the influencing factors affecting the choice of adaptation methods in crop, livestock and mixed crop-livestock production systems as well as the perceptions of and adaptation to climate change in Africa at regional level. Results from these studies are highly aggregated and the parameters have a limited value in identifying country specific impacts and adaptation methods given the heterogeneity of the countries that were studied. Moreover, attempts have also been made to analyse the vulnerability of Ethiopian farmers to climatic and non climatic shocks by using panel data sets. While informative and methodologically sound, these studies are limited by their sample of 15 villages which hardly represent the vast agro-ecology and socio-economic diversity of the country.

This study focused on two central themes to address the gaps of knowledge mentioned above. The first theme is the analysis of the vulnerability of farmers to climate change at household and regional levels. The second theme is the study of adaptation to climate change by farmers, including the determinants of adaptation measures and factors influencing the perceptions of climate change in the Nile Basin of Ethiopia.

The household-level vulnerability analysis assesses the vulnerability of farmers to climatic extreme events by employing the vulnerability as expected poverty approach. The vulnerability to expected poverty approach is based on estimating the probability that a given shock or set of shocks moves consumption by households below a given minimum level (such as a consumption poverty line) or forces the consumption level to stay below the given minimum requirement if it is already below this level. The regional-level vulnerability study analyses the vulnerability of Ethiopian farmers to climate change based on the integrated vulnerability assessment approach using vulnerability indicators for Ethiopian regional states. The vulnerability indicators include a series of different socio-economic and biophysical attributes of Ethiopia's seven agriculture-based regional states. The various socio-economic and biophysical indicators have been classified into three classes, based on the Intergovernmental Panel on Climate Change's (IPCC 2001) definition of vulnerability, which consists of adaptive capacity, sensitivity and exposure. The method of principal components analysis (PCA) was employed to assign weights to selected indicators in the calculation of vulnerability indices for each region.

Using data from a survey of 1,000 households across 5 regional states and 20 districts, the household level vulnerability study showed that the percentages of households that reported droughts, floods and hailstorms over the prior five years were 31 percent, 12 percent and 18 percent, respectively. These shocks resulted in a variety of reported losses, primarily consisting of a decline in crop yields and asset/income losses. The majority of farmers did nothing to respond to these shocks, mainly due to poverty. Among those farmers who did respond, selling livestock was the most common approach to cope with climate shocks, suggesting that in addition to serving as a source of power for farming and manure for fertilizing soil, livestock serves as a store of wealth providing insurance against shocks. Results also indicate that vulnerability is highly sensitive to a minimum income requirement (poverty line) that farm households require to survive on a daily basis. For example, when the daily minimum income is fixed at US$0.3 per day, only 7 percent of farmers are vulnerable to future climate change, whereas at a minimum income level of US$2 per day, 93 percent of the farmers are vulnerable to climate extremes. Results also indicate that farmers in the Kola (warm semi-arid) agro-ecological zone are most vulnerable among the agro-ecologies that were surveyed. The results further reveal that highly impoverished households who have limited access to basic services and wealth are more vulnerable to extreme climate than households with better access to basic services and wealth.

Policies should encourage income generation and asset holding especially livestock, both of which will enable consumption smoothing during and immediately after harsh climatic events. Moreover, government policies should focus on: the investment on basic services; the inception of old age insurance; the provision of agro-ecology-based technology packages; the strengthening of productive safety net programmes; provision for weather-indexed drought insurance especially in the most vulnerable agro-ecologies; and the development of well-coordinated early warning systems.

The results from the regional-level analysis show that the relatively less-developed, semi-arid and arid regions, namely Afar and Somali, are highly vulnerable to climate change. The large Oromia region, which is characterised both by areas of good agricultural production in the highlands and midlands and by recurrent droughts especially in the lowlands, is also vulnerable. Furthermore, the Tigray region, which experiences recurring droughts, is also vulnerable to the negative impacts of climate change in comparison with the other regions. Results imply that the major reason for disparity among regions is associated with the low level of development and poverty. Integrated rural development policies aimed at alleviating poverty can play a double role in reducing poverty and increasing adaptive capacity to climate change. Special emphasis should be placed on the relatively less-developed regions of the country (i.e. Afar and Somali), as well as the relatively more populated regions (e.g. Oromia and Tigray), in terms of investment in technology, institutions and infrastructure. In addition, investment in irrigation in places with a high potential for irrigation (e.g. SNNP) can increase the country’s food supply. This supply could then be stored and sold during droughts instead of depending on food aid from other nations.

The second theme analysed the factors affecting the perceptions of and adaptation to climate change based on a household survey of a total of 1000 mixed crop and livestock farmers during the 2004/2005 production year in the Nile Basin of Ethiopia. Farmers were asked if they had perceived any change in the patterns of rainfall and temperature over the past 20 years. The majority of farmers indicated that they had observed an increase in temperature and a decrease in rainfall. Farmers who claimed to have observed a change in climate were further asked if they had adapted. Accordingly, some of those who claimed to have observed climate change indicated that they have adapted by adopting different methods. The remaining farmers who have observed and did not adapt to climate change indicated a lack of information on the types of adaptation methods and a lack of money as the major barriers to adaptation

Government policies should strengthen the existing adaptation strategies practiced by farmers and support the adoption of adaptation technologies that have the potential to reduce damages at the farm level, such as: crop and livestock diversification; the use of drought-tolerant crop varieties and livestock species; water harvesting; and resource conservation and management practices. Policies that avail information on the type of adaptation methods and provide financial resources to support adaptation should be targeted to ease the constraints to adaptation.

To analyse the factors affecting the perception of and adaptation to climate change, this study employed the Heckman's sample selection model. The Heckman's sample selection model enables the analysis of adaptation as a two-stage process involving perception and adaptation stages. The first stage assesses whether the respondent perceived climate change or not, and the second stage assesses whether the respondent adapted to climate change that is to say if he or she had perceived a change in climate in the first stage. Results from the first stage regression indicate that: the age of the head of the household; farm income; information on climate change; farmer-to-farmer extension; number of relatives in a *Got* (village); and agro-ecological settings affect the perception of climate change. Thus, older farmers; better-off farmers; better-informed farmers; and those with stronger social networks are more likely to perceive climate change. Contrary to previous expectations, farmers living in Dega (highlands) perceived more change in climate than farmers in Kola (lowlands) when compared with Weynadega (midlands). This could either be associated with the recent drought (in 2002), or it can be linked to various environmental changes, particularly severe deforestation in that region, which have contributed to reduced water availability (Meze-Hausken 2004).

Results from the second stage regression of the Heckman's sample selection model indicate that: the education of the head of the household; household size; the gender of the head of the household being male; livestock ownership; the extension on crop and livestock production; the available credit; and temperature affect adaptation to climate change. Government policies and investment strategies that support the provision of and access to education, credit, extension services on crop and livestock production, and information on climate and adaptation measures are necessary to better adapt to climate change in Ethiopia. Policy interventions that encourage informal social networks (financially or materially) can promote group discussions and better information flows and enhance adaptation to climate change. Moreover, results indicating significant differences among regions, suggest that adaptation technologies should be targeted to the various agro-ecologies to enhance their specific and unique adaptation potential.

6.2 Limitations of the study and areas for further research

This study has limitations that future studies need to address. The first limitation is the assumption that cross-sectional variability captures temporal variability in the household level vulnerability analysis. This assumption was followed due to the absence of panel data that capture household characteristics before and after shocks have been experienced. Despite its limitations, very important information has been generated. Basing future research on panel data can therefore yield more sound results. The second limitation of the study is the choice of the scale of the analysis for the regional level vulnerability study which is highly aggregated at a regional level. Each region included in this study covers a very wide area of land characterised by different biophysical and socio-economic attributes. These variations within each region should be considered in order to target areas that are highly vulnerable and to recommend appropriate interventions. The results of this study indicate the general features of each included region. Future research should focus on local levels, especially district or village levels, where actual dynamics of vulnerability to climate change take place.

The other limitation of the study is the use of a household unit as a scale of analysis in the adaptation study. Even though climate change does not vary across different plots of a given household, adaptation practices could vary across different plots given the different plot characteristics which could dictate the use of different methods for an optimising farmer.

Adaptation takes place at a plot level where actual agricultural practices take place and thus future research should focus on identifying plot characteristics and adaptation methods practiced in each plots.

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Appendices

Appendix 1: Indicators of wealth

Region	Quality of houses	Radio	Livestock	Non-agricultural income	Gifts and remittance
Afar	9.25	25.48	42.4400	1.82	
Amhara	27.88	11.18	46.4500	2.60	0.08
Benishangul-Gumuz	8.96	23.32	30.6425	4.44	
Oromia	23.21	23.20	46.7475	3.89	0.02
SNNP	11.44	18.28	41.8425	6.20	0.01
Somali	7.30	18.66	55.6875	7.45	0.17
Tigray	21.25	21.73	45.1775	2.71	0.02

Appendix 2: Technology

Region	Insecticides and pesticides	Fertilizer supply	Improved seeds
Afar	4.61	1.50	4.47
Amhara	11.31	14.11	13.46
Benishangul-Gumuz	15.97	18.47	19.48
Oromia	14.65	16.99	15.82
SNNP	18.91	21.41	21.00
Somali	1.94	2.18	1.94
Tigray	11.05	12.34	10.22

Appendix 3: Infrastructure and institutions

Region	Health services	All-weather roads	Food market	Primary and secondary schools	Telephone services	Micro-finance	Veterinary services
Afar	28.11	33.86	23.68	25.595	13.16	0.22	15.98
Amhara	10.18	14.84	19.11	25.305	3.89	6.83	15.26
Benishangul-Gumuz	11.21	19.97	24.13	22.885	3.52	2.38	21.42
Oromia	15.72	19.66	26.27	25.430	6.04	3.47	13.86
SNNP	18.55	26.53	42.06	31.935	7.08	5.91	20.11
Somali	8.66	30.59	19.11	13.880	6.87	0.04	2.01
Tigray	13.13	32.04	14.66	25.970	5.72	9.26	24.61

Appendix 4: Irrigation potential and literacy rate

Region	Irrigation potential	Literacy rate
Afar	1.62	16.85
Amhara	3.14	26.61
Benishangul-Gumuz	2.46	31.42
Oromia	3.82	31.07
SNNP	6.23	34.92
Somali	1.84	12.74
Tigray	5.99	37.04

Appendix 5: Frequency of drought and flood over the past 100 years

Region	Frequency of droughts and floods
Afar	9
Amhara	15
Benishangul-Gumuz	9
Oromia	14
SNNP	10
Somali	14
Tigray	12

Appendix 6: Change in climatic conditions

Region	Increasing temperature	Percentage change in precipitation
Afar	2.74	1.03
Amhara	2.64	1.01
Benishangul-Gumuz	2.53	0.99
Oromia	2.51	0.97
SNNP	2.41	0.88
Somali	2.55	1.29
Tigray	2.76	1.12

Appendix 7: Normalised values of the original data by their respective means and standard deviations

Region	Quality of house	Ownership of livestock	Ownership of radio	Non-agricultural income	Gifts and remittance	Insecticide supply	Fertilizer supply	Enhanced seeds supply	Health services
Afar	–0.769	–0.227	1.094	–1.142	–0.890	–1.081	–1.401	–1.088	1.956
Amhara	1.482	0.308	–1.906	–0.761	0.297	0.017	0.215	0.155	–0.736
Benishangul-Gumuz	–0.804	–1.801	0.641	0.137	–0.890	0.781	0.774	0.987	–0.581
Oromia	0.918	0.348	0.616	–0.131	–0.593	0.565	0.585	0.481	0.096
SNNP	–0.504	–0.307	–0.416	0.997	–0.741	1.263	1.151	1.197	0.521
Somali	–1.004	1.541	–0.337	1.608	1.631	–1.519	–1.314	–1.438	–0.964
Tigray	0.681	0.138	0.307	–0.708	–0.593	–0.026	–0.011	–0.293	–0.293

All-weather roads	Food market	Primary and secondary schools	Telephone services	Veterinary services	Irrigation potential	Literacy rate	Drought sand floods	Increasing temperature	Change in precipitation
1.169	–0.053	0.216	2.05	–0.027	–1.045	–1.131	–1.123	1.141	–0.061
–1.445	–0.571	0.162	–0.852	–0.126	–0.237	–0.068	1.235	0.413	–0.231
–0.740	–0.002	–0.285	–0.968	0.717	–0.600	0.456	–1.123	–0.485	–0.418
–0.783	0.241	0.185	–0.179	–0.317	0.126	0.418	0.842	–0.634	–0.547
0.161	2.032	1.388	0.147	0.537	1.406	0.837	–0.730	–1.414	–1.226
0.719	–0.571	–1.950	0.081	–1.937	–0.930	–1.579	0.842	–0.351	1.906
0.918	–1.076	0.285	–0.279	1.153	1.278	1.068	0.056	1.33	0.578