Linking Vulnerability, Adaptation and Food Security in a Changing Climate: Evidence from Muger Sub-Basin of the Upper Blue-Nile Basin of Ethiopia

Abayineh Amare

A Dissertation Submitted to
Center for Environment and Development Studies, College of Development Studies

Presented in the Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Development Studies (Environment and Development Studies)

Addis Ababa University,
Addis Ababa, Ethiopia
June, 2018

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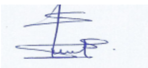
Declaration

I, the undersigned, declare that this is my original work, has never been presented in this or any other University, and that all the resources and materials used for the dissertation, have been fully acknowledged.

Name:-__Abayineh Amare

Signature: 

Date: - June 05, 2018

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Date of submission June 05, 2018

This dissertation has been submitted for examination with my approval as University supervisor.

Supervisor name: - Belay Simane (PhD.)

 Signature:

Date: - June 05, 2018

Dissertation Approval
Addis Ababa University

School Of Graduate Studies

This is to certify that the thesis prepared by "Abayineh Amare" entitled: *Linking Vulnerability, Adaptation, and Food Security in a Changing Climate: Evidence from Muger Sub-Basin of the Upper Blue-Nile Basin of Ethiopia* and submitted in fulfilment of the requirement for the Degree of Doctor of Philosophy (Environment and Development Studies) complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

Signed by the Examining Committee:

Feyera Senbeta ---------- June 05, 2018

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Tilahun Amede ---------- June 05, 2018

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iii

Linking Vulnerability, Adaptation and Food Security in a Changing Climate: Evidence from Muger Sub-Basin of the Upper Blue-Nile Basin of Ethiopia

ABSTRACT

Ethiopia has been deemed a climate 'hot-spot'- a place where a changing climate pose grave threats to agricultural production, food security and human well-being. The objectives of this study are *to estimate and compare the level of vulnerability of smallholder farmers' to climate change and variability; to explore adaptation options and identify factors influencing farmers' decisions to adopt adaptation options; to examine the food security status and determinants of household food security; and to evaluate the impact of adoption of adaptation options on household food security in the Muger sub-basin of the upper Blue-Nile of Ethiopia. The research used Focussed Group Discussions, key informant interviews and a semi-structured questionnaire survey of 442 sampled households to collect data across three different agro-ecological zones in the sub-basin. The study used descriptive methods, index, and econometrics models to analyse the collected data. Descriptive statistics such as frequency, mean, chi-square, t-tests, and one way ANOVA were used. Livelihood vulnerability index, household food balance model, binary logit model, multinomial logit model, and propensity score matching were used to analyse the data. The results reveal that along with the different agro-ecological zones, households experienced different degrees of vulnerability. Kolla agroecology exhibits relatively low adaptive capacity, higher sensitivity and higher exposure to climate change and variability that is deemed to be the most vulnerable agro-ecology. Dega agro-ecology has least vulnerable owing to its higher adaptive capacity, lower sensitivity and exposure. Results signify that small-scale irrigation, agronomic practices, livelihood diversification, and soil and water conservation measures are the dominant adaptation options that smallholder farmers used to limit the negative impact of climate change and variability in the study area. The results further reveal that adoption of small-scale irrigation is significantly and positively influenced by access to credit, social capital, and the educational status of household heads. Crop failure experience and access to early warning system positively affected the use of agronomic practices, while distance to marketplace and size of farmland have a negative influence. The results also point out that adoption of soil and water conservation measures are positively affected by early warning systems, distance to the marketplace, and size of cultivated land. It is also noted that livelihood diversification is negatively influenced by socio-economic factors such as education, gender of the household head, and livestock ownership. The household food security analysis results show that 57.8% of the households are food secure, while the remaining 42.2% of the households are food insecure. Soil and water conservation, small-scale irrigation, and employing different agronomic practices are important factors influencing household food security. Moreover, landholding and livestock ownership positively and significantly affect household's food security, while family size and distance to the nearest market affect food security negatively. The results further reveal that farmers adopting any of the adaptation options had higher food calorie intake per day per adult equivalent than those who did not. These results suggest that designing agroecology based resilience-building adaptation strategies is crucial to reduce the vulnerability of smallholder farmers to climate change and variability. A policy that promotes the adoption of soil and water conservation measures, small-scale irrigation, agronomic practices, and livelihood diversification strategies should be central to food security strategy in the study area. The results suggest that improved policies aimed at increasing the adoption of adaptation options to off-set the impact of climate change and variability should focus on: creating effective micro-finance institutions and effective early warning systems, increasing farmer awareness, improving infrastructure, and encouraging farmers' membership to many social groups. The results further suggest that agro-ecological and gender-based research should be promoted and increased for a more holistic understanding of farmer adaptation options.*

Keywords: *vulnerability, exposure, sensitivity, adaptive capacity, adaptation, food security, Muger sub-basin.*

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DEDICATION

This thesis is dedicated to my son, Nahom Abayineh.

List of original papers

This dissertation is based on the following five original papers, which are listed from 1 –5.

Paper 1. Amare, A. & Simane, B. (2017). Climate Change Induced Vulnerability of Smallholder Farmers: Agroecology-Based Analysis in the Muger Sub-Basin of the Upper Blue-Nile Basin of Ethiopia, *American Journal of Climate Change*, *6*: 668-693. DOI: 10.4236/ajcc.2017.64034.

Paper 2. Amare, A. and Simane, B. (2017). Determinants of smallholder farmers' decision to adopt adaptation options to climate change and variability in the Muger Sub basin of the Upper Blue Nile basin of Ethiopia, *Journal of Agriculture and Food security*, 6:64. DOI 10.1186/s40066-017-0144-2.

Paper 3. Amare, A and Simane, B. (2017). Convenient Solution for convenient truth: Adoption of soil and water conservation measures for climate change and variability in Kuyu District of Ethiopia, in W. Leal Filho et al. (eds.), Climate Change Adaptation in Africa, Climate Change Management, Springer International Publishing AG 2017.

Paper 4. Amare, A. & Simane, B. (2017). Assessment of Household Food Security in the Face of Climate Change and Variability in the Upper Blue-Nile of Ethiopia, *Journal of Agricultural Science and Technology B* 7, 285-300. Doi: 10.17265/2161-6264/2017.04.006

Paper 5. Amare, A. and Simane, B. (2018). Does adaptation to climate change and variability provides household food security? Evidence from Muger sub-basin of the Upper Blue-Nile, Ethiopia, *Journal of Ecological Process, 7(13): 1-12. Doi:* 10.1186/s13717-018-0124-x

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1. Background of the Study

Climate change represents one of the humanity's greatest challenges of the 21st century. The continued ascent of our species depends to a significant extent on our ability to limit further catastrophic changes to the climate and to adapt to both past and future changes. In many parts of the world, changes in climatic variables – including incessant increases in temperature and declines in precipitation – are already having detrimental impacts on food security, human health, energy, biodiversity, etc (Thornton *et al*. 2011;Schlenker and Lobell, 2010). Some of these impacts further alter the climate – e.g. plant biodiversity loss reduces CO_2 sequestration, contributing to temperature rises – creating positive feedback loops with increasingly perilous consequences for humanity (IPCC, 2014; FAO, 2005). The poor countries, in particular, are the most vulnerable because of their high dependency on ecosystem goods and services that are susceptible to and their limited capacity to adapt to a changing climate (Review, 2016; MEA, 2005).

Climate change impacts are widely observed in Africa where it has directly affected climate-dependent activities (Orindi & Murray, 2005). According to IPCC (2014), Africa is one of the most vulnerable continents to climate change and variability because of multiple stresses and its low adaptive capacity. Boko *et al.* (2007) report that agricultural production and food security in many African countries are likely to be severely compromised by climate change and variability. Ethiopia is often cited as one of the most vulnerable and with the least capacity to respond and adapt to climate variability and change (Bewket *et al*. 2015; Conway & Schipper, 2011; World Bank, 2010; Parry *et al*. 2007). The prevailing low adaptive capacity of the poorest populations will also contribute to the vulnerability of this change (Gebrehiwot & Veen, 2013).

Ethiopia has historically suffered from climatic variability and extremes (IIRR, 2007; Pankhurst, 1985; Mesfin, 1984). Droughts and floods are common phenomena in Ethiopia, occurring every 3 to 5 years (World Bank, 2006). The country has experienced at least five major national droughts since the 1980s (World Bank, 2006), along with dozens of local droughts (World Bank, 2009). A recent study by FAO (2010) further indicated that in the past 15 years, the country has been hit by climate change induced disasters about 15 times. Over the years, the frequency of droughts and floods has increased in many areas resulting in serious consequences for the country’s economy in general, and agriculture and food security in particular (Gebrehiwot & Veen, 2013; Mesfin, 1984). Specifically, reports point to the increased incidence of meteorological drought episodes, food shortages and climate-sensitive human and crop diseases in the northern highland and southern lowland regions of the country (UN-ISDR, 2010; Aklilu & Alebachew, 2009; World Bank, 2009). Climate change is expected to further exacerbate the frequency and intensity of rainfall variability and associated drought and flood disasters in Ethiopia (NMA, 2006).

Analysis of historical climate data in Ethiopia shows an increase in mean annual temperature by 1.3°C between 1960 and 2006, with an average rate of 0.28°C per decade. The annual minimum temperature increased by about 0.37°C every decade between 1951 and 2006 (McSweeney *et al*. 2008). In contrast, precipitation remained fairly stable when averaged over the country (Schneider *et al*. 2008). No statistically significant trend in mean annual rainfall was observed in any season from 1960-2006 (McSweeney *et al.* 2008; NMA, 2006). The results of IPCC‟s mid-range emission scenario show that as compared to the 1961-1990, average mean annual temperature across Ethiopia will increase between 0.9°C and 1.1°C by the year 2030 and from 1.7°C to 2.1°C by the year 2050. The temperature across the country could rise by between 0.5°C and 3.6°C by the year 2080, whereas precipitation is expected to show some increase (NMA, 2006). When the scenario in the period 1960-1990 is compared to the period 2030-2050, annual precipitation shows a change between 0.6% and 4.9% to 1.1% and 18.2%, respectively (NMA, 2006). The percentage change in seasonal rainfall is expected to be up to 12% over most parts of the country (ICPAC, 2007). The increasing temperature combined with rainfall variability became the reason for the decline of agricultural produce in Ethiopia (Bewket *et al.* 2015). The situation is exacerbated by the high dependence on climate-sensitive natural resources base and rain-fed agriculture with a low level of technological application to agriculture. Climate change and its associated variability are emphasized as one of the major sources of a challenge for agriculture, food security, and livelihoods which could increase the country’s vulnerability to a variety of stresses (FDRE, 2011)**.**

Ethiopia’s agriculture, which is the mainstay of the country’s economy constituting 42.9% the nation’s gross domestic product (GDP) and generates more than 85% of the foreign exchange earnings, and serves as the main base for food security is mainly rain fed (MoFED, 2013), thus highly exposed to climate variability and extremes (Bewket *et al.* 2015; Teshome *et al*. 2008). The potential adverse effects of climate change on Ethiopia’s agricultural sector are a major concern, particularly given the country's dependence on agricultural production. A study by UNDP (2008) further indicated that long-term climate change in Ethiopia is associated with changes in rainfall patterns and variability, and temperature, which could increase the country's frequency of both droughts and floods. These climatic hazards, particularly drought, are becoming the major forces challenging the livelihoods of most farmers in Ethiopia (Bewket *et al.* 2015). The rural population, for whom agriculture is the primary source of food, direct and/or indirect employment and income, will be most affected due agriculture's vulnerability to climate changes and its associated variability.

For instance, World Bank reported that rainfall variability already costs the Ethiopian economy by 38% of its growth potential (World Bank, 2006a)**.** Similarly, a study using Ricardian method showed that a unit increase in temperature could result in a reduction of the net revenue per hectare by US$177.62 in summer and US$464.71 in winter seasons (Deressa, 2007). Expected impact of climate change and its associated variability on crop production in different part of Ethiopia are change of bimodal rainfall into mono-modal pattern; reduction in crop yields and in some years complete crop failure; increased crop pest and weed prevalence; increased rainfall intensity resulting in serious soil erosion; extensive flooding often leading to crop destruction, livestock deaths, landslides and road blockage (Bewket *et al*. 2015)**.** Due to its adverse effects on agriculture and livelihoods, climate change is expected to have a negative impact on food security (Kassie *et al. 2015*; Niang *et al*. 2014; Thornton *et al*. 2011). The study by Kassie *et al. (2015)* in the central Rift valley of Ethiopia using three General Circulation Models reveals that maize yield decrease on average by 20% in 2050s as compared to 1980-2009, due to climate change. Albers *et al.* (2016) showed that in 2016, the country struck by severe droughts that reduced livestock and agricultural output and increased malnutrition for approximately 10 million people. FAO (2016) also noted that extreme floods have disrupted planting and displaced over 100,000 people. It is well recognized that the most vulnerable and marginalized communities and groups are those who experience the greatest impacts (IPCC, 2007a), and are in the greatest need of support and adaptation strategies. Left unmanaged, climate change and variability will reverse development progress made so far and compromise the well-being of the people, particularly the rural farmers', whose livelihoods depend largely on rain-fed agriculture (Gebrehiwot & Veen, 2013)**.** So, adapting to climate change impacts become a necessity in order to minimize its consequences on human well-being and on the environment (Sonwa *et al*. 2010; Locatelli *et al.* 2008).

Against this backdrop, the significance of adaptation is recognized at international and national policy debates on climate change and variability, likewise the literature on climate change and agriculture have increasingly directed attention to the issue of adaptation (Smit & Pilifosova, 2001; Smit *et.al*. 2000). Adaptation of the agricultural sector to the adverse effects of climate change will be imperative to protect the livelihoods of the poor and to ensure food security (Niang *et al.* 2014). Studies (IPCC, 2012; Bryan *et al.* 2009; Adger, 2007) argued that adaptation has the potential to reduce vulnerability of rural communities to climate change and variability by making them better able to adjust and cope with adverse consequences. Adapting to climate change requires a combination of various individual responses at the farm-level and assumes that farmers have access to alternative practices and technologies available in their area. It also involves changes in agricultural management practices in response to changes in climate conditions for an agrarian community (Charles and Rashid, 2007). Adaptation of people to different hazards vary from household to households and region to region, and its effectiveness depends on local institutions and socio-economic setting to increase the resilience of affected individuals (Morton, 2007). Given the above differences, a wide range of adaptation options was reported to better cope with erratic rainfall and drought risk both in the highlands and lowlands of the country (NMA, 2007). For example, recent assessment of agricultural adaptation in different part of Ethiopia revealed that farmers are adapting to these changes by using integrated watershed management with emphasis on soil and water conservation; in-situ rainwater harvesting practices; use of small-scale irrigation for fruit and vegetable production; diversification of household income sources; establishment of area enclosures; and planting early-maturing and/or drought-resistant crops, among others (Belay *et al*. 2017; Ng'ang'a *et al*. 2016; Tesfahunegn *et al.* 2016; Bewket *et al*. 2015)**.** Despite the concerted efforts made to adapt, the adoption of those adaptation options to reduce household vulnerability to climate change and variability were below expectation and climate change and its associated extreme events-drought and flood-continued to be a serious problem in Ethiopia (Bewket *et al*. 2015; NMA, 2007). Similarly, Muger sub-basin is not an exception to this impact.

Similar to other parts of Ethiopia, Muger sub-basin is one of the vulnerable areas to climate change and variability. It is suffering from climate upheavals, which have become common natural disasters in the country. The observation shows that smallholder farmers in Muger sub-basin have been repeatedly affected by rainfall scarcity and associated drought. There is erratic rainfall in the rainy seasons, bringing drought and reduction in crop yields and pasture productivity; the rainfall, especially in the later rains toward the end of the year, has been reported as coming in more intense and destructive downpours, bringing floods, landslides, and soil erosion (Denekew & Bekele, 2009). In addition, there has been an increase in temperature which disturbs the physiology of crops, the micro-climate, and the soil system on which they grow. The food insecurity situation in the Muger sub-basin shares similar features with that of the Country. In this respect, farmers' food security in Muger sub-basin is under threat of being adversely impacted by climate change and variability.

Despite concern on the potential adverse effects of climate change on Ethiopia's agricultural sector, high recognition of adaptation to reduce vulnerability to climate change and enhance household food security by making rural communities better able to adjust to the changing climate, help them to cope with adverse consequences, and moderate potential damages are badly needed (IPCC, 2014). Thus, a research need to be enhanced to better understand farmers' vulnerability to climate change and variability, to identify adaptation options farmers used, and to evaluate the potential impact of adaptation on farmers food security that would support adaptation process through policies and programs guided by scientific evidence.

1.2. Problem Statement

At the core of the ongoing debate regarding the implication of climate change in Sub-Saharan Africa, food security issue is central. Climate variability, particularly rainfall variability and associated droughts and floods have been causing food insecurity in Ethiopia (Rosell, 2011; Seleshi & Zanke, 2004). Climate change is expected to pose more challenges and to further reduce the performance of the economy (Arndt *et al.* 2011). A study on mapping poverty and vulnerability in Africa identified Ethiopia as one of the countries' most vulnerable to climate variability and change (Thornton *et al*. 2006). The country's economy heavily relies upon the agricultural sector, which is mostly rain-fed. Ethiopia's vulnerability is indeed largely due to climatic conditions. This has been demonstrated by the devastating effects of various prolonged droughts and floods. The productive performance of agricultural sector has been severely compromised by climate change and variability. For instance, agricultural Gross Domestic Product (GDP) and per capita cereal production has been falling over the last forty years with cereal yield stagnant at about 1.2 tons per hectare. Empirical evidence reveals that adverse changes in climate, combined with long-term factors (technology, environmental, institutional) led to soil degradation and a decline in yield per hectare (Anley *et al.* 2007; Shiferaw & Holden, 1999). In addition to that, the impacts of climate change on livestock are also felt from an increased severity and frequency of drought. Deterioration of pastures during droughts periods have resulted in poor health and death of livestock impacting food and livelihood of smallholder farmers *(*Bewket *et al. 2015;* Niang *et al.* 2014; NMA, 2007).

There is emerging consensus that adaptation options are urgently needed to minimize climate impacts (Rosenzweig *et al*. 2013). Recognizing adaptation as a critical response to the impacts of climate variability and change, different national policies, programs and strategies that intend to address the impact of climate change have been designed by the Ethiopian government (NPC, 2016; EPCC, 2015; FDRE, 2011; MoFED, 2010; NMA, 2007; MoFED, 2006). On the other side, local communities have been adapting to climate change and variability so as to minimize its adverse impact and to supports them in producing enough foods to meet their nutritional needs. For instance, rural communities made concerted efforts in adopting water harvesting technologies and soil conservation measures such as constructing stone terraces and soil bunds, establishing enclosures and participating in tree planting programs since last few decades. Despite the progress made so far to design and implement such policies and strategies, and promote adaptation options, the level of adoption of adaptation options that would reduce vulnerability and enhance food security is below expectation (EPCC, 2015).

Many studies have been undertaken to assess climate change vulnerability (Pandey *et al*. 2015; Odjugo 2010; Pearson and Langridge, 2008; Deressa, 2007). The primary focus of these studies are bio-physical aspect of vulnerability to specified change in climate. These partial assessments are limited to integrate the socio-economic aspect with bio-physical aspect of vulnerability. Although there are few studies (Simane *et al.* 2016; Tagel & Anne van der, 2013; Tesso *et al.* 2012a; Abera *et al*. 2011; Abate, 2009; Deressa *et al*. 2008) that attempted to develop a research framework which integrate bio-physical and socio-economic aspects of livelihood vulnerability, considerable geographical variations in the level of exposure and vulnerability to extreme events in the scale of analysis got little attention. For instance, Deressa *et al.* (2008) assessed the vulnerability of Ethiopian farmers to climate change based on the integrated vulnerability assessment approach using vulnerability indicators. However, within countries like Ethiopia, with diverse topography, as well as a varying level of socio-economic and infrastructure development, aggregated national vulnerability assessments likely mask differences in vulnerability between different agro-ecological zones at sub-basin level. As a result, an estimate of vulnerability at national, or state scale is inadequate to capture the full range of climate vulnerabilities among different agro-ecological zones (Simane *et al*. 2016).

Despite the presence of dramatic spatial heterogeneity (i.e. in soil qualities, steepness of slopes, and access to infrastructure), socio-economic, and environmental diversity in the Muger sub-basin of the upper Blue-Nile basin, Simane *et al.* (2016) is the only study in Choke Mountain that investigates the role of agro-ecosystem specific vulnerability to design effective resilience-building interventions. Yet, there is limited scientific evidence that enables feasible development policy interventions that strengthen effective adaptation options intended to improve food security of the people in the sub-basin. This problem calls the need to understand local vulnerability to climate change and variability, and to understand the reasons for their vulnerability to better adapt to climate risks and promote adaptation options for local communities.

Different studies have been undertaken (Deressa, 2007; NMA, 2007; Kidane *et al*. 2006) to estimate the impact of climate change on agriculture. These studies provide limited insight in to adaptation process. The impact models do not investigate the practical feasibility of adaptations, the conditions that might facilitate or impede adoption of adaptive options, or the actual types of adaptations employed (Adger and Kelly, 1999). Like a considerable progress made so far to assess adaptation options in response to climate change and variability, growing researches seek to understand the underlying factors affecting farmers decision to adopt adaptation options (Balew *et al*. 2014; Debalke, 2014; Wood *et al*., 2014; Tesso *et al*. 2012b; Tazeze *et al*. 2012; Deressa *et al*. 2009; Hassan & Nhemachena, 2008; Kurukulasuriya & Mendelsohn, 2008; Seo & Mendelsohn, 2008). Although these studies provide important information on factors regulating the decision to adopt, the results are not conclusive and there is no consistency in the outcomes of studies regarding the type of adaptation options and its determinant factors. The major challenge is that climate change adaptation is not a one-size fits all phenomenon; adaptation options will vary across regions (Berry *et al*. 2006) based on agro-ecological contexts, socio-economic factors (Adger *et al*. 2009), climatic impacts, and existing infrastructure and capacity. Given these heterogeneity of different areas, targeting the right adaptation options to different community remains a big challenge. This suggests that an adaptation options and a factor in a certain locality at a time might not be true in another locality. It is therefore, vital that initiatives for a better understanding of climate adaptation, and factors determine the choice of adaptation options perused by farmers since farmers' responses to climate change or their choice of adaptation options varies with respect to socio-economic, institutional, biophysical, and environmental factors. Understanding, household's responses to risks related to climate change and variability as well as their decision process to adopt adaptation options are of utmost importance to provide them with tailored sets of adaptation options and provides informed decision to make the most of these adaptation options on their livelihood outcomes. The knowledge on confluence of factors assists policy to strengthen adaptation that would help to improve household food security.

Most of the research on climate change impacts related to food security in Africa, as evident in IPCC assessments, focuses on changes in crop yields and food production (Niang *et al*. 2014; Porter *et al*. 2014; Kurukulasuriya and Mendelsohn, 2008; Seo and Mendelsohn, 2008; Gregory *et al*. 2005; Fuhrer, 2003). For instance, the experimental findings on wheat and rice by Gregory *et al*. (2005) reveals that decreased crop duration and yield of wheat was observed as a consequence of warming. Fuher (2003) have further assessed the potential consequences of change in climate on the growth and yield of crop plants, concluding that the earlier anticipated benefits of co_2 fertilization would be largely offset by nutrient limitations, pollutants and further interaction with climatic factors. These impact studies provide important information on sensitivities of various attributes of crop systems to a specified change in climate (Lobell *et al*. 2008; Thornton *et al*. 2011). Notwithstanding several research efforts, mentioned above, to understand the impact of climate change and its associated variability on food security that merely focus on bio-physical aspects of production, none of these studies have looked into the potential benefits that adaptation generate. Micro evidence on the impact of adaptation perused by farm households on household food security is scanty.

To the best of my knowledge, Ali & Erenstein (2017); Asfaw *et al*. (2015); Gebrehiwot & Van Der Veen (2015) and Falco *et al*. (2011) are the only studies that attempt to measure the impact of adaptation on food security. While these impact studies provide valuable information on how adaptation to long term change in climatic norms is likely to affect yields and crop production, food security is concerned not only with issues of food availability, but also with access to and utilization. Moreover, the results from these studies are highly fragmented, and inadequate to address local context and different dimensions of household food security. For instance, study by Falco *et al*. (2011) which focus only on agricultural productivity provides a partial assessment of food security-adaptation relationship. The current study aims to investigate how farmer’s decision to adopt adaptation in response climate change and variability affects household food security in the study locality. This seems particularly relevant because most of the debate on the effect of climate change in agriculture has been focusing on the impact of climate change rather than on the role of adaptation.

Altogether, despite efforts of few studies that examined household vulnerability to climate change (Simane *et al.* 2016; Tagel & Anne van der, 2013; Tesso, *et al.* 2012a; Abera *et al*. 2011; Abate, 2009; Deressa *et al*. 2008; Yesuf & Bluffstone, 2007) and determinants of farmers choice of adaptation practices (Balew *et al*. 2014; Debalke, 2014; Wood *et al*., 2014; Tesso *et al*. 2012b; Tazeze *et al*. 2012; Deressa *et al*. 2009; Hassan & Nhemachena, 2008; Kurukulasuriya & Mendelsohn, 2008; Seo & Mendelsohn, 2008), studies on linking three bodies of scholarship that are inherently interconnected: vulnerability, adaptation, and food security, are scarce. This limits to craft an adaptation polices which is vital to inform and support farmers decision under a changing climate, and programs that recognize the livelihoods of the vulnerable people. The aggregate nature of previous studies, however, makes it very difficult to provide insights into differentiated livelihood vulnerability to climate change and variability between agro-ecological zones, and how effective adaptation options at micro or farm household level buffer against climate change and play a crucial role in improving the food security status of farm households. Thus, the current study allows policy makers to understand patterns of vulnerability among agro-ecology, and decision patterns of farmers to adopt adaptation options that help to make informed policy decision. Furthermore, the findings of the study brings the potential benefit that adaptation generates to food security to the spotlight.

To fill these gaps, in-depth investigation of agro-ecology specific vulnerability and an understanding of the socio-economic, environmental, and institutional compulsions and constraints of smallholder farmers in adopting adaptation options for achieving household food security are imperative. Therefore, the main purpose of the present study is to critically examine the three fields of research- vulnerability, adaptation options, and food security relationship - of smallholder farmers in the Muger sub-basin.

1.3. Objectives of the Research

The overall objective of this research is to examine climate change vulnerability, adaptation and food security relationship of smallholder farmers in Muger sub-basin of the upper Blue-Nile basin. The specific objectives of the research are to:

1. assess the differentiated vulnerability of smallholder farmers to climate variability and change among three agro-ecological zones;
2. identify adaptation options, that is a set of strategies implemented in response to long-run changes in key climatic variables such as temperature and rainfall;

3. identify factors constraining/facilitating farmers' decision to adopt adaptation options in response to climate change and variability;
4. assess the status and determinants of food security of smallholder farmers' in the face of climate change in the sub-basin; and
5. evaluate the impact of adoption of adaptation to climate change and variability on household food security.

1.4. Research Questions

This research attempted to answer the following central research questions;

1. What are the exposure, sensitivity and adaptive capacity profiles of smallholder farmers?
2. What are the adaptation options so far developed by the smallholder farmers in response to climate change and variability?
3. What are the determinants of farmer's decisions to adopt adaptation options to climate change and variability?
4. What is the status of household food security in the sub-basin?
5. What are the socio-economic, institutional, environmental, and demographic factors determine household food security in the Sub-basin?
6. Does adoption of adaptation to climate change and variability provides household food security?

1.5. Significance of the Study

This study provides empirical evidence that link vulnerability, adaptation and food security to guide informed policy decisions. The study contributes scientific knowledge on the agro-ecology specific vulnerability of smallholder farmers to the adverse impacts of climate variability and change. Furthermore, the study sets a stage for an understanding of adaptation options employed by local people in adapting to impacts of climate change and variability for plausible sub-basin specific intervention. Likewise, assessing factors influencing rural household food security is very crucial as it provides information on household food security status that would help the policy makers for effective implementation of food security program. The study further provides information on the potential benefit that adaptation generate to improve household food security, and this information helps policy makers to give emphasis in adaptation in the process of policy design.

The findings of the study have important policy relevance that aimed at enhancing smallholder farmers' adaptive capacity and reducing exposure, and sensitivity to climate change and variability. Specifically, the government of Ethiopia is currently implementing the Growth and Transformation plan-II whose goal, among other things, ensuring sustainability of the environment and climate change adaptation and mitigation. This research, therefore, stands to provide significant policy recommendations that would contribute to the attainment of the goal and provides a venue to understand and learn from the current adaptation that would serve for future improvement. In general, the study provides an adequate understanding of the factors that contribute to the particular vulnerability of the rural farm households, and improved understanding of the potential benefits generated from adaptation. Akin, it might help in guiding intervention directions for the improvement of household food security situation. Furthermore, the findings of this study could enrich the literature on vulnerability, adaptation options being employed by subsistence farmers, and food security particularly in developing countries.

1.6. Scope and limitation of the Study

This study draws on a comprehensive framework or perspective of social-economic vulnerability whereby underlying vulnerability factors, adaptation options, and the impact of adaptation on household food security can be better captured. Consequently, smallholder farmers have been responding by taking adaptive responses and strategies. These modes of adaptation, in turn, have led them to reduce household food insecurity. Therefore, this study aims at understanding and explaining such impacts which have resulted from adaptation options implemented by smallholder households in response to climate change and variability.

This study used indicator-based vulnerability assessment that allows to customize the indicators in the study context. Challenges prevail in terms of selecting suitable indicators and assigning appropriate weights to them. The weakness of the indicator approach is that there is some level of subjectivity in choosing indicators (Etwire *et al*. 2013) and the local environment plays a significant role in framing and designing the indicators. Extensive review of the literature, consultation of subject experts, as done in this study, would be expected to lead to good results. Furthermore, due to differences in Livelihood Vulnerability Index (LVI) indicators between studies, numerical values of LVI can be used to compare the level of vulnerability within a study, for example between agro-ecological zones in our sample, but cannot be readily compared with other studies as the indicators and context vary. Further, although the adaptive capacity, sensitivity and exposure factors may be meaningfully compared between agro-ecological zones, the formula for the overall LVI-IPCC score should be used with caution, as it leads to the counter intuitive result that if the adaptive capacity factor is numerically greater than the exposure factor, increased sensitivity actually reduces vulnerability.

In addition to this, this study used cross-sectional data and analysed the problem of food security at one point in time. This might not be enough to generate adequate information to address the dynamics of food security because there could be many variables which could potentially be changed from one season to another season within a given locality. As a result, this study is limited in using panel data that would help to address the changing variables over time that could help to understand the dynamics of vulnerability and food security which are inherently affected by seasonality. The study also used household food balance model to assess the status of household food security. However, the concept of food security is a multidimensional and this demands methodological pluralism.

1.7. Theoretical Framework

This study is framed in the lens of a blend of different theories, approaches and explanations. Sustainable Livelihood Framework (SLF) was adopted as one of the theoretical foundation to guide the assessment of livelihood vulnerability to climate change and its associated extreme events-drought and floods. This framework helps to understand the link among livelihood vulnerability in a vulnerability context, adaptation options and household food security. The sustainable livelihood framework consists of five blocks: the vulnerability context; livelihood assets; policy, institutions and processes; livelihood strategies; and livelihood outcomes. In the context of this study, vulnerability context refers the climate change and its associated variability-drought and floods- is major determinant of sustainability of livelihood assets as it directly influences livelihood strategies, institutional process and livelihood outcomes of community (DFID, 2000; Chambers and Conway, 1992). The livelihood asset block is the state of the ownership and control of the combination of assets, or capital types, that smallholder farmers have with which to respond to vulnerability. Policy, institutions and processes describes the structures and processes that affect access and influence of adaptation options, the combination and type of livelihood assets and the vulnerability context. In this study context, policy and legislation issues have got less attention because most of the policy, and legislation issues should be seen at larger scale of analysis than the household level of analysis.

Livelihood strategies refers to a range of adaptation options that farmers used in response to climate change and to achieve their livelihood outcomes. The livelihood outcome describes the achievements or outputs of the adaptation options and may include reduced vulnerability and increased food security (DFID, 2000; Chambers & Conway, 1992).

The underlying assumption in SLF is that people pursue their livelihood outcomes (such as reduced vulnerability, and improved food security) based on a range of livelihood assets through the use of a variety of adaptation options. The adaptation options that people use to generate livelihood outcomes and the way they reinvest in asset building are driven by the transforming structures such as government or private sectors and by the institutional structures such as culture, norms, values and formal laws (DFID, 1999; Farrington *et al*. 1999).

The study used SLF because it is an important tool that helps to understand the link among vulnerability to climate change, adaptation options, and food security in a systematic and holistic ways. It provides a framework for analysing adaptation options and livelihood assets that determine vulnerability and food security and the contextual factors that influence them (Eakin & Luers, 2006). The inter relations among vulnerability context; livelihood assets; institutions and organizations that shape or constrains both livelihood assets and adaptation options that farmers used; and the livelihood outcomes resulted from this process and its impact on livelihood assets are portrayed in Figure 1.1.

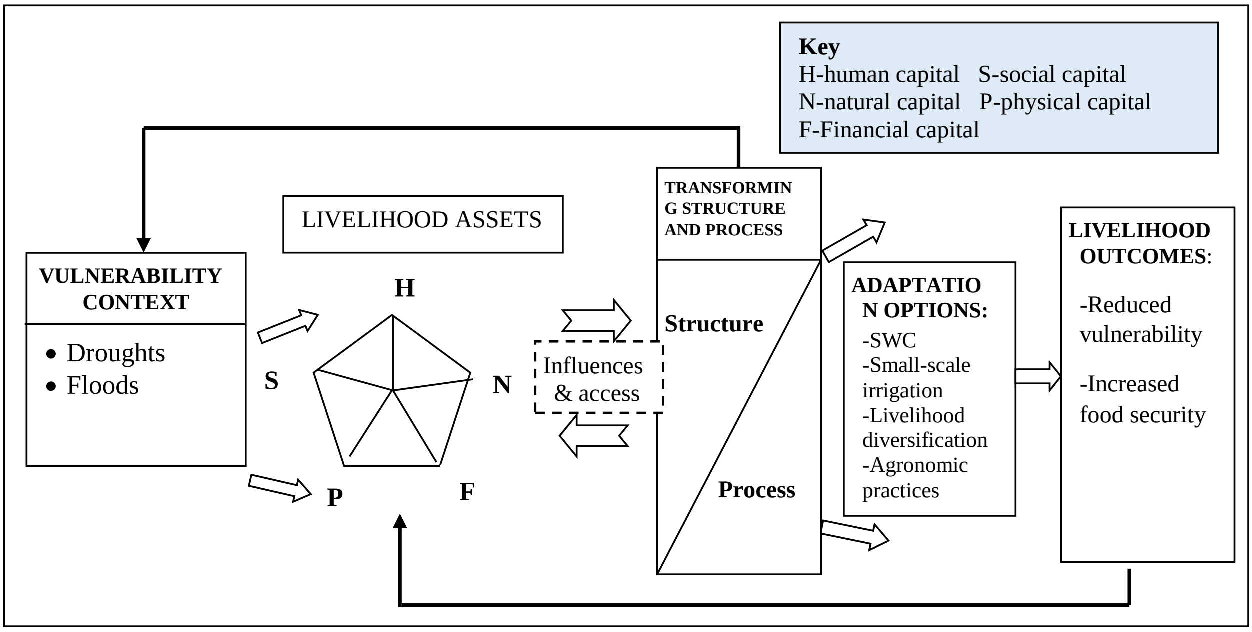


Figure 1.1: Sustainable livelihood framework

This framework has proven useful for assessing the ability of households to withstand shocks such as droughts and floods. However, the Sustainable Livelihoods Approach to a limited extent addresses the issues of sensitivity and adaptive capacity to climate change, but a new approach for vulnerability assessment that integrates climate exposures and accounts for household adaptation practices is needed in order to comprehensively evaluate livelihood risks resulting from climate change. The risk-hazard approach, political-economy approach, and integrated approach used to frame vulnerability analysis in addition to SLF were described in chapter two of this thesis. The demographic, environmental, political-economy, and economic explanations were used to frame food security analysis and presented in chapter four.

1.8. Research Methodology

1.8.1. The Muger river sub-basin: an overview

Bio-Physical Setting

This study was conducted in the Muger sub-basin of the upper Blue-Nile basin. Muger sub-basin cover a total area of 8,188 km2. Muger River flows from the southeast of the basin into upper Blue-Nile River. The altitude in Muger sub-basin ranges between 953 masl and 3550 masl. The highlands in the eastern and southern part of the sub-basin are higher in altitude, greater than 2600 meters up to 3550 meters. The lowlands along the Muger River have lower altitude less than 1700 masl (Denekew & Bekele, 2009).

Following Hurni (1998) classification of agro-ecological zones of Ethiopia, *Kolla* agroecology (lowland) is characterized by relatively hotter and drier climate, whereas *Weyina Dega* (middle land) and *Dega* agroecology (highland) are wetter and cooler. Using this classification, the sub-basin of the study area contains *Kolla, Woyina Dega*, and *Dega* agro-ecological zones (Figure 1.2). Evidence revealed that farmers living in different agro-ecological settings have their own choice of adaptation methods (Legesse *et al*. 2013; Tessema, *et al*. 2013; Deressa *et al*. 2009). Moreover, there exist a considerable variations in farmer's vulnerability to climate change among different agro-ecological zones in the sub-basin emanated from geographical and socio-economic variation among agro-ecological zones.

The sub-basin has an annual rainfall varies between 833 mm and 1326 mm. Lower annual rainfall ranging from 833 mm up to 1000 mm is observed along the river and lowlands. Relatively high rainfall is found in the highlands of the sub-basin. The annual maximum and minimum temperature of the sub-basin varies between 16^0C -31.5^0C and 3^0C -16.5^0C, respectively. Temperature is higher along the river with a maximum of 28^0C-31.5^0C and minimum of 13^0C -16.5^0C. The sub-basin is characterized by tepid to cool moist highlands. The northwestern part of the lowlands is hot to warm moist lowlands (Denekew & Bekele, 2009).

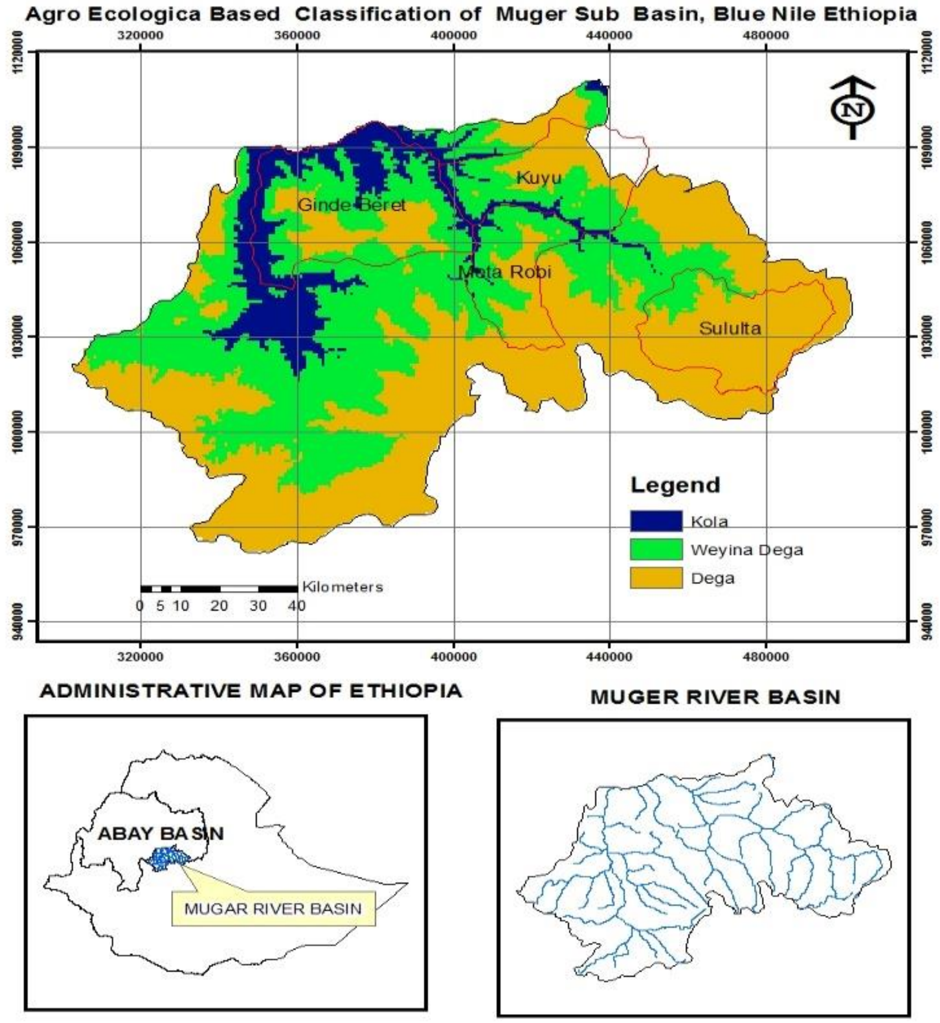
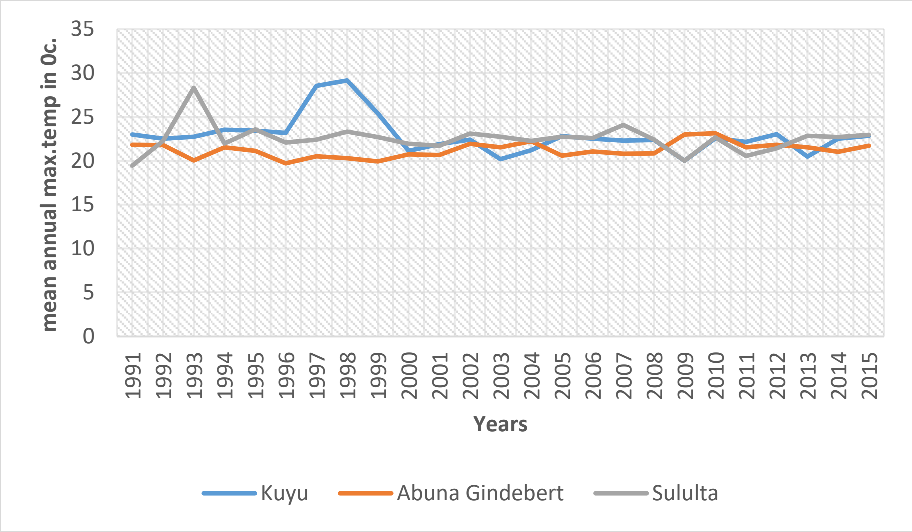


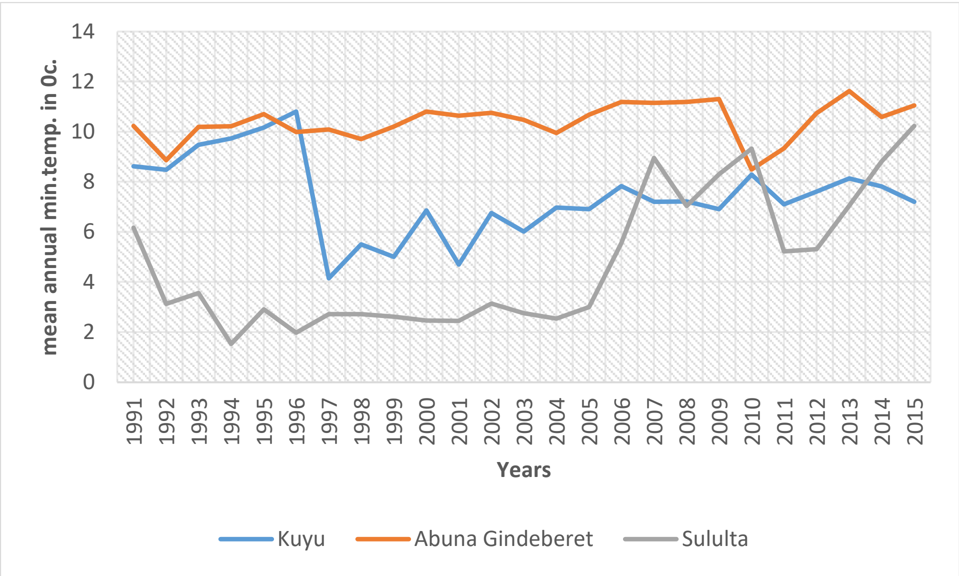
Figure 1.2: Agroecology-based classification of Muger sub-basin of the upper Blue-Nile

Besides the biophysical characteristics of the sub-basin, Figure 1.3 and 1.4 present the trend in the annual maximum and minimum temperature data from the year 1990-2015 for the three metrology stations found in the sampled districts namely Geberegurach station for the kuyu district, Sululta station for the sululta district, and Kachisi station for Abuna Gindeberet district, respectively. Although the mean of maximum temperature at Abuna Gindebert and Sululta districts more or less constant over years, an increasing trend is observed at Kuyu district between the years 1996-2000.



Source: NMA, 2015.

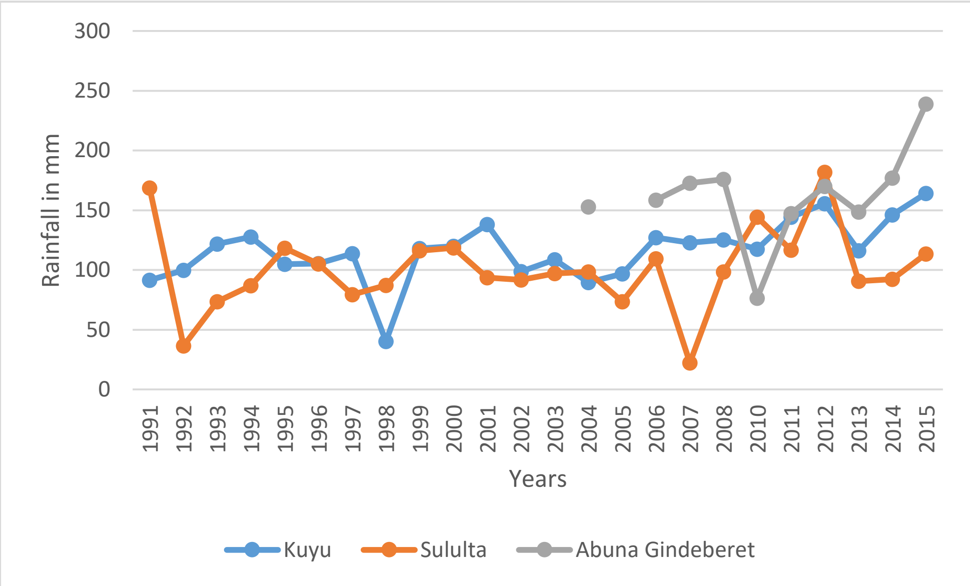
Figure 1.3: Trends of mean annual maximum temperature in sampled districts, 1991–2015.



Source: NMA, 2015.

Figure 1.4: Trends of mean annual minimum temperature in sampled districts, 1991–2015.

Similarly, Figure 1.5 illustrates the trend in the annual precipitation in the selected stations. The mean annual temperature and rainfall records over the period under consideration were computed from the daily temperature and rainfall records obtained from each metrology station. The rainfall trend suggests a fluctuating and general decline in rainfall values over the study area. The results show a noticeable decline is observed in Sululta district in rainfall values from 1991-1992 and from 2006-2007. The result further shows that a noticeable decline in rainfall is observed from 1997-1998 in Kuyu district. It is this variability that created a decline in crop production and productivity and/or a total crop failure due to insufficient rainfall during the production seasons in the study area. This problem is more prevalent in Abuna Gindeberet district where most of the area of the district fall under *kolla* agro-ecological zone.



Source: NMA, 2015.

Figure 1.5: Trends of mean annual rainfall in sampled districts, 1991–2015.

The major soils of the sub-basin are Leptosols, Luvisols, Vertisols, Fluvisols, and Alisols. Leptosols represents the most widely occurring soils within the sub-basin. The second dominant soil is Luvisols. Small patches of Cambisols, Nitosols and Rigosols are also seen in some parts of the sub-basin.

Socio-Economic Setting

According to the current zonal structure, the sub-basin is shared between three zones: North Shoa, West Shoa, and Oromia Regional State of Finfine special zone. Muger sub-basin covers 15 weredas; Ejersa (Addis Alem), Walmara, Juldu, Mulo, Sululta, Adda Berga, Meta Robi, Yaya Gulelena Debre Libanos, Wichalena Jido, Ginde Beret, Kuyu, Kutaya, Gerar Jarso, Degem, and Wara Jarso . The total population of the sub-basin is 2,442,247 people (Denekew & Bekele, 2009) The sub-basin is predominantly rural in character and the farmers are engaged in small-scale and subsistence mixed agriculture. The dominant sources of livelihoods in the sub-basin are crop production and livestock rearing.

Muger sub-basin falls under three major livelihood zones includes: 1). *Abay- Muger -Jemma Sorghum and Teff Belt* Livelihood Zone where its category of food economy is mixed farming and its basic economic activities lie on crop and livestock production; 2). *Ambo Selale Ginde-Beret Teff and Wheat* Livelihood Zone which is characterised by mixed crop and livestock production.; and 3). *Selale-Ambo Highland Barley, Wheat and Horse bean Belt* Livelihood Zone with an economy characterized by the cultivation of rain-fed cereals complemented by livestock rearing and sales of trees and fodder (Denekew and Bekele, 2009).

1.8.2. Philosophical underpinning: debates between qualitative and quantitative approaches

It is recognized that the way in which research is conducted may be conceived of in terms of the research philosophy subscribed to, the research strategy used and so the research instruments utilized. Before discussing the specific methods that were applied in generating the main field data for this research, we briefly overview the distinction between qualitative and quantitative approaches in relation to debates between the proponents of the two, and the challenges and the opportunities for applying mixed methods to understand social realities.

The quantitative paradigm is based on positivism. Reality is stable and can be observed and described from an objective viewpoint (Levin, 1988), i.e. without interfering with the phenomena being studied. The ontological position of the quantitative paradigm is that there is only one truth, an objective reality that exists independent of human perception. Epistemologically, the investigator and investigated are independent entities. The goal is to measure and analyse causal relationships between variables within a value-free framework (Denzin and Lincoln, 1994). Quantitative methods are regarded as the only means for investigating and communicating results to audiences. In contrast, these stands of positivism were highly criticized and their application to understanding social phenomena was questioned. It disregards the fact that many human (i.e., subjective) decisions are made throughout the research process and that researchers are members of various social groups.

In response to this, a new idea proposing the reconsideration of the ontological, epistemological and axiological stands of positivism emerged under the name of post-positivism which is named as constructionist, interpretationist and naturalist. The qualitative paradigm is based on interpretivist (Secker *et al.* 1995; Altheide & Johnson, 1994; Kuzel & Like, 1991) and constructivism (Guba & Lincoln, 1994). Ontologically speaking, there are multiple realities or multiple truths based on one's construction of reality. Reality is socially constructed (Berger & Luckmann, 1966) and so is constantly changing. On an epistemological level, there is no access to reality independent of our minds, no external referent by which to compare claims of truth (Smith, 1983). The investigator and the object of study are interactively linked so that findings are mutually created within the context of the situation which shapes the inquiry (Denzin and Lincoln, 1994; Guba and Lincoln, 1994). This suggests that reality has no existence prior to the activity of investigation, and reality ceases to exist when we no longer focus on it (Smith, 1983). The emphasis of qualitative research is on process and meanings.

Some authors describe this difference as '*paradigm purity'* and relate it to the issue of '*incompatibility thesis'*, the central argument of which is that by no means should a researcher mix the two methods in studying social phenomena. In this respect, Tashakkori and Teddlie (1998) stated: *Compatibility between quantitative and qualitative methods is impossible due to the incompatibility of paradigms that underline the methods. Researchers who try to combine two methods are doomed to failure due to inherent differences in philosophies underlying them*. In a similar way, Hughes *et al.* (2000) emphasize the urgency of adopting ethnographic methods that allow a better understanding of rural societies within the domain of rural geography. They assert that inter-textuality and the subjectivity of knowledge are the main cause of the change in methodology from quantitative research strategies to more in-depth qualitative techniques.

1.8.3. Arguments presented for mixed-method research

Having discussed some of the basic philosophical assumptions of the two paradigms, we are better able to address the arguments given for combining quantitative and qualitative methods in a single study. There have been a few theorists (Datta, 1994; Reichardt & Rallis, 1994) who have counteracted the argument of incompatibility and who have suggested the possibility of the co-existence of the quantitative and qualitative approaches, and how mixing them could enhance an understanding of social realities. This has contributed considerably to the emergence of the new approach known as '*pragmatism 'or 'compatibility theses*. It is an approach under which one can generate data by multiple methods from both qualitative and quantitative traditions.

In this connection, as noted by Reichardt and Rallis (1994) the two paradigms are thought to be compatible because they share the tenets of theory-ladenness of facts, the fallibility of knowledge, in-determination of theory by the fact, and a value-ladened inquiry process. They are also united by a shared commitment to understanding and improving the human condition, a common goal of disseminating knowledge for practical use, and a shared commitment for rigor, conscientiousness, and critique in the research process. In fact, Casebeer and Verhoef (1997) argued qualitative and quantitative methods as part of a continuum of research with specific techniques selected based on the research objective.

Haase and Myers (1988) point out that the two approaches can be combined because they share the goal of understanding the world in which we live. King *et al.* (1994) claim that both qualitative and quantitative research share a unified logic and that the same rules of inference apply to both. According to Tashakkori and Teddlie (1998), mixed method studies are those that combine the qualitative and quantitative approaches to the research methodology of a single study or multi-phased study. Closely tied to the arguments for integrating qualitative and quantitative approaches are the reasons given for legitimately combining them. Literature on research methodology identified purposes of mixing methods: 1) triangulations or seeking convergence of results-combining two or more theories or sources of data to study the same phenomenon in order to gain a more complete understanding of it (Denzin and Lincoln, 1994); 2) complementarity or examining overlapping and different facets of a phenomena; 3) initiation or discovering paradoxes, contradictions and fresh perspectives; 4) development or using the methods sequentially such as the results from the first method inform the use of the second method; and 5) expansion or mixed methods adding breadth and scope to the project' (Greene *et al.* 1989). Given the above-stated importance of mixing qualitative and quantitative methods, the current study draws its methodological framework from mixed method approach.

1.8.4. Sampling design

The research design was based on three-stage sampling procedure. In the first stage, the whole sub-basin constituting fifteen districts was grouped into three strata (*Kolla, Woyina Dega, and Dega* agro-ecological zones) based on their agro-ecological characteristics including the rainfall, soil, and topography. The intention of this grouping was to maintain the representativeness of the samples that have been selected. *Kolla* refers to an area with an altitude ranging between 500 and 1500 m asl, with mean annual temperature between 20 and 28^0C and annual rainfall between 600 and 900 mm. *Woyina Dega* refers an altitude ranging between 1500 and 2300 m asl, with mean annual temperature 16 and 20 ^{0}C and annual rainfall above 900 mm; and *Dega* refers with an altitude between 2300 and 3200 m asl, with mean annual temperature between 6 and 16 ^{0}C and mean annual rainfall above 900mm (Hurni, 1998). This helped to group districts' having the same features and characteristics' in to one category. Then, two districts which have dominantly *kolla* and *Dega* features, namely Abuna Gindeberet from *Kolla,* and Sululta from *Dega* agro-ecological zones were randomly selected. Similarly, Kuyu and Meta Robi districts which share dominantly *Woyina Dega* features were also selected from *Woyina Dega* agro-ecology using simple random sampling technique. In the second stage, only Kebeles which share the dominant features of each sampled district were listed in consultation with agricultural experts in the study area. This is mainly to exclude Kebeles which do not share the dominant features of that particular district. Then, a total of sixteen Kebeles, four Kebeles from each sampled district, were randomly selected. Finally, a total 442 sample respondents-143 from *Kolla*, 200 from *Woyina Dega*, and 99 from *Dega* agro-ecological zones were selected using simple random sampling technique on the basis of probability proportional to size (PPS). The sampling frame was the list of households which was obtained from the Kebeles administration. Households for Focussed Group Discussions (FGDs) were also drawn from each identified district, and a member of the group was identified with the help of development agents working in the area.

1.8.5. Sample size determination

Determining an appropriate sample size is a very important in any research as samples that are too small may hardly represent the population and lead to erroneous findings and recommendations. There are several approaches suggested to determine sample size. These include using a census for small populations, imitating a sample size of similar studies, using published tables, and using specified formulas to determine sample size (Israel, 1992). The aim of the calculation is to determine an adequate sample size with a good precision. However, this is influenced by a number of factors, including the purpose of the study, population size, the risk of selecting a "bad" sample, and the allowable sampling error. In addition to the purpose of the study and population size, three criteria usually need to be specified to determine the appropriate sample size: the level of precision, the level of confidence or risk, and the degree of variability in the attributes being measured (Miaoulis & Michener, 1976).

In order to determine the sample size, this research adopted the following formula drawing on Kothari (2004).

$$n = \frac{z^2 \cdot p \cdot q \cdot N}{e^2 \,(N-1) + z^2 \cdot p \cdot q}$$

Where,

n is the desired sample size for the study; ***Z*** is the upper points $\alpha/2$ of standard normal distribution at 95% confidence level, which is equal to 1.96; ***e*** is acceptable error at a given precision rate (assumed 5%); ***p*** is the proportion of households (which is taken as 0.5 or 50%)- most conservative case that *'n'* will be the maximum and the sample will yield at least the desired precision; ***q*** is *1-p;* ***N*** is the total households in the Muger sub-basin equals to 323, 791(CSA, 2007) . The above formula yields a maximum sample size of 442.

1.8.6. Data sources and methods of data collection

Both primary and secondary data were gathered and used for this study. In view of the diverse impact of climate change and variability on smallholder farmers and the nature of the information needed on various aspects of this research, employing a single method of data collection method is insufficient to satisfy data requirements. Therefore, this demands a mixed method of data collection methods to generate adequate and reliable data that would be enhanced through triangulation. Many authors advocate this approach in such a way that it makes possible to develop an integrated system in which the first method sequentially informs the second method, contradictions and fresh perspectives appear, and different facets of the phenomena emerge in order to keep the data both comprehensive and authentic (Swanson, 1992; Greene *et al*. 1989; Mathison, 1988) . In similar vein, the present study used mixed methods of data collection to collect quantitative and qualitative data from primary and secondary sources as described below;

Primary data collection methods

1) Household Survey**:** The primary data was gathered from selected respondents from June to October, 2015 in the Muger sub-basin of the upper Blue-Nile basin. In order to adequately address the research questions of this research, we employed semi-structured interview schedule. The interview schedule was designed based on three central research theme-vulnerability, adaptation, and food security-that this study aimed to address. The survey addressed data on ten "major components" related to vulnerability such as soil and water, agriculture, food, asset, livelihood strategies, innovation, infrastructure, socio-demographic, social network, and natural disaster and climate variability. Moreover, this survey instrument includes questions that helped to investigate whether farm households made some adjustments in their farming in response to long-term changes in mean temperature and rainfall by adopting soil and water conservation measures, small-scale irrigation, livelihood diversification strategies, and different agronomic practices as adaptation options. Besides data on lists of adaptation options, the survey instrument included factors that limit/aid adaptation options to change in mean temperature and rainfall, and extreme events over the last five years in the study area.

In order to capture the net available food by each of the sampled households in the sub-basin ,sort of questions were included to investigate total grain produced by household, total grain purchased by household, total grain obtained through food-for-work by household, total relief grain food received by household, and total crop utilized for seed by household. Furthermore, to examine determinants of household food security, data were collected on demographic characteristics, asset possession, off-farm/non-farm income, livestock ownership, and institutional arrangements. Additional data on resource endowment, institutional factors such as access to credit and training, use of external farm inputs and access to extension services, problems in crop and animal production, pest infestation, productive resources and biophysical factors were gathered using this interview schedule. Moreover, early warning system, social capital, and experience of crop failure were addressed in the survey.

The interview schedule was pre-tested prior to conducting the formal survey by administering it to selected respondents. On the basis of the results obtained from the pre-test, the necessary modification was made on the interview schedule. Training on methods of data collection and the contents of the interview schedule was given to selected enumerators. Finally, the survey was conducted under the close supervision of the researcher.

2) Focused Group Discussions (FGDs)**:** Group discussions are said to build up collective and creative enthusiasm, which leads to sharing familiarizing new ideas and concepts with an outsider who then familiarize with them (Chambers, 1992). One particular powerful strategy to properly employ FGDs is to bring participants together with a common background with the issue under discussion. Getting groups' opinions, attitudes, and views are necessary requirement to elaborate, clarify and cross-check ideas, experiences and arguments obtained through other methods. Based on this argument and to have detail information that has been useful to draw the right conclusion from the survey work, qualitative information was gathered from purposively selected respondent farmers, development agents, and community leaders using checklists. Collection of primary qualitative information was managed through holding a discussion with the focused group to generate information on the factors influencing farmers' decision to adapt a sets of strategies in response to climate change. Moreover, they were asked questions related to causes of vulnerability and food insecurity, barriers to adaptation options, and the impact of those adaptation options on household food security.

Based on depth and sufficiency of the data needed to meet the purposes of the study and redundancy of data collected, we have conducted a total of ten FGDs of which four were in *Woyina Dega*, and three in each of the other two agro-ecological zones. The focus groups were composed of six to eight elderly. One focus group in each agroecology was composed of women, while the other focus groups were composed of men whom we think (as suggested by local community and development agents) that have rich information on climate change, adaptation, and food security. The discussions were directed by the enumerators assisted by the researcher.

3) Key Informant Interview**:** In-depth interviews with purposively selected key informants were undertaken. Key informant interviews likewise, enabled the study to obtain climate information from people with long-term experience in the area as well as expert knowledge thus counterchecking the credibility of data from other sources. This method was conducted in two ways. One is guided by general interview guide (checklist questions), and the second is an informal conversational interview conducted spontaneously. The informants include elders, religious leader, local level officials and experts who lived and served longer in the locality. Topics treated includes major constraints to crop and livestock production, any change they experienced in climate conditions of their local areas over the past 20–30 years, causes and effects of the observed change, adaptive responses to the observed changes and effects and barriers for successful adaptation.

Secondary data collection methods

Secondary data were gathered to supplement primary data obtained. Documents, reports, and records maintained at Development Agents (DAs) centers, and districts agricultural offices were consulted as major sources of secondary data. In addition to this, in order to determine patterns and trend of climate variability and change in the study area, the present study used two key climate variables namely rainfall (precipitation) and temperatures. Monthly rainfall and temperature data for the period of 1991-2015 were obtained from the Meteorological stations found in the sampled districts and subjected to trend analyses. The IPCC (2007) defines climate in a wider sense is the state, including a statistical description, of the climate system particularly precipitation, temperature, and wind. The classical period of time is 30 years, as defined by the World Meteorological Organization (WMO). It is against this criterion that the study seeks to use climate data collected over the past 25 years.

1.9. Organization of the Thesis

This thesis is organized in six chapters. This introductory chapter gives the research context and research questions, general theoretical framework and direction in research design. Chapter Two presents farmers vulnerability to climate change and variability among three different agro-ecological settings. Chapter Three describes adaptation options and presents factors that determine farmer’s decision to adopt adaptation options. The status of household food security and its determinants are presented in chapter Four. The impact of adaptation on household food security is explained in chapter Five. Finally, chapter Six presents a synthesis of the main results of the previous chapters and described scientific insights and implications for climate risk management and issues for further research.

2. CLIMATE CHANGE INDUCED VULNERABILITY OF SMALLHOLDER FARMERS: AGROECOLOGY-BASED ANALYSIS IN THE MUGER SUB- BASIN OF THE UPPER BLUE-NILE BASIN OF ETHIOPIA

ABSTRACT

Ethiopia is frequently identified as a country that is highly vulnerable to climate variability and change. The potential adverse effects of climate change on Ethiopia's agricultural sector are a major concern, particularly given the country's dependence on agricultural production which is sensitive to climate change and variability. This problem calls the need to understand agro-ecology based vulnerability to climate change and variability to better adapt to climate risks and promote strategies for local communities so as to enhance food security. The objective of this study is to estimate and compare the level of vulnerability of smallholder farmers' to climate change and variability from three agro-ecological zones representing Muger sub-basin of the upper Blue Nile basin using Livelihood Vulnerability Index. The research used quantitative and qualitative data collected through Focussed Group Discussions, key informant interviews and a questionnaire survey of 442 sampled households across three different agro-ecological zones in the sub-basin. The results reveal that along with the different agro-ecological zones, households experience different degree of vulnerability. These differences are largely explained by differences in exposure, sensitivity and adaptive capacity of smallholder farmers. The livelihood vulnerability analysis reveals that Kolla agro-ecology exhibits relatively low adaptive capacity, higher sensitivity and higher exposure to climate change and variability that is deemed to be the most vulnerable agro-ecology. These contributing factors to a vulnerability in Kolla agro-ecology are largely influenced by assets, livelihood diversification, innovation, infrastructure, socio-demographic factors, social capital, agriculture, food security, and natural disasters and climate variability. The result furthermore shows that Dega agro-ecology has least vulnerable owing to its higher adaptive capacity coupled to its less exposure and sensitivity. These results suggest that designing agro-ecology based resilience-building interventions is crucial to reduce the vulnerability of smallholder farmers to climate change and variability.

Keywords: vulnerability, exposure, sensitivity, adaptive capacity, Muger sub-basin.

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2.1. Introduction

Climate change impacts are widely observed in Africa where it has directly affected climate-dependent activities (Orindi & Murray, 2005). According to IPCC (2014), Africa is one of the most vulnerable continents to climate change and variability because of multiple stresses and its low adaptive capacity. Boko *et al*. (2007) report that agricultural production and food security in many African countries are likely to be severely compromised by climate change and climate variability.

Like other African countries, Ethiopia is also frequently identified as a country that is highly vulnerable to climate variability and change (Conway & Schipper, 2011; World Bank, 2010; Parry *et al*. 2007). Ethiopia's agriculture, which is the mainstay of the country's economy constituting 42.9% of the nation's Gross Domestic Product (GDP) and generates more than 85% of the foreign exchange earnings is mainly rain-fed and heavily depends on rainfall (Ministry of Finance and Economic Development (MoFED) 2013). Climate change is a major concern in Ethiopia because of its potential adverse effects on Ethiopia's agricultural sector, particularly given the country's dependence on agriculture. In the last 50 years, the annual average minimum temperature in Ethiopia has shown an increasing trend of 0.2^{o}C every decade (EPCC, 2015). Reports indicate that there have been major droughts in Ethiopia over the past centuries, 15 of which, in fact, occurred in the last 50 years leading to major losses or suffering in human as well as loss of livestock due to a shortage of water and grazing lands (Mamo *et al*. 2013).

According to UNDP (2008) report, long-term climate change in Ethiopia is associated with changes in rainfall patterns and variability, and temperature, which could increase the country's frequency of both droughts and floods. Livelihoods of most smallholder farmers in Ethiopia is challenged by these climatic hazards, particularly drought and floods (Bewket *et al.* 2015). There is an emerging consensus that vulnerability to climate change is a product of large inter-annual climate variability and an economy that is highly dependent on agriculture (Byerlee *et al*. 2007) as well as institutional factors that can create socio-economic crises even in the absence of a large meteorological anomaly (Simane et al. 2016; Smakhtin & Schipper, 2008). A major challenge is that vulnerability is context specific and varies across different agroecology based on differences in agro-ecological setting, socio-economic factors, climatic impacts, and existing infrastructure and capacity (Simane *et al*. 2016).

It should be noted that vulnerability is defined differently in different disciplines (Füssel, 2007; Gallopín, 2006). This study situates vulnerability by Intergovernmental Panel on Climate Change (IPCC) stated as '*the degree to which a system is susceptible to and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity'* (IPCC, 2007a).

While it is increasingly accepted that climate change and variability will be Ethiopian farmers' greatest challenge, only a few studies have been undertaken in Ethiopia concerning livelihood vulnerability to climate change and variability. Most of these literature have been focussed on assessing vulnerability of specific sectors such as agriculture, water resources, health, forestry, and to lesser extent socio-economic analysis to the changing climate (Pandey *et al*. 2015; Odjugo, 2010; Pearson and Langridge, 2008; Deressa, 2007). These studies most often consider bio-physical vulnerability in isolation and provide little insights on integrated bio-physical and socio-economic aspects of livelihood vulnerability. Nonetheless, studies developed explicitly in the context of an integrated assessment of livelihood vulnerability to climate change and variability is limited. Important exceptions are Simane *et al.* (2016); Tagel & Anne van der (2013); Tesso, *et al.* (2012a); Abera *et al*. (2011); Abate (2009); Deressa *et al*. (2008).

There is emerging a consensus that livelihood vulnerability to the changing climate varies with the scale of analysis. It is noted that vulnerability assessed at the national level can conceal variations in local vulnerability (Brooks *et al.* 2005). Notwithstanding of this understanding, much of the studies that have been undertaken to assess climate change vulnerability were at a national level but failed to address local context. For instance, the study by Deressa *et al.* (2008) and Tagel & Anne van der (2013) to assess farmers vulnerability to climate change and variability do not take into account the spatial heterogeneity between agro-ecological zones, varying level of socio-economic and infrastructure development, households access to resources, level of food insecurity, and the ability to cope. This type of analysis is often overlooked local variations and inadequate to capture the full range of climate vulnerability among different agro-ecological zones. To the best of our knowledge, (Simane *et al.* 2016) is the only study attempted to assess livelihood vulnerability to climate change specific to agroecosystems. This problem calls the need to understand agroecology based vulnerability to climate change and variability to better adapt to climate risks and promote tailored adaptation options for local communities so as to enhance food security. Investigating farmer's vulnerability to changing climate and variability by effectively identifying exposure, sensitivity, and adaptive capacity is the starting point to identify and promote adaptation options in effect improve household food security. Since little has been studied regarding agro-ecological based farmers vulnerability, and explicitly in the study area which is affected and expected to be harshly affected by the changing climate, livelihood vulnerability assessment is timely and essential.

The findings of the research can assist to identify the most vulnerable agro-ecological zones and to facilitate the understanding of specific factors contribute for farmers vulnerability to climate change and variability. This could provide a support for decision about targeting interventions and priority setting at the agroecology level in reducing vulnerability against adverse effects of this change. The general objective of this study is to assess and compare the level of vulnerability of smallholder farmers resulted from differences in socio-economic, environmental and existing institutional factors among three agro-ecological zones in the Muger sub-basin. The specific objective is to examine exposure, sensitivity and adaptive capacity profiles of smallholder farmers in the sub-basin.

2.2. Definitions of Concepts

Vulnerability: The growing body of literature on vulnerability and adaptation contains a sometimes bewildering array of terms: vulnerability, sensitivity, resilience, adaptation, adaptive capacity, risk, hazard, adaptation baseline and so on (IPCC, 2007; Adger *et al*. 2002; Burton *et al*. 2002). There exists a strong recognition that different authors conceptualize vulnerability in different ways based on their areas of concern, objectives to be achieved and the methodologies employed when they used it in a different context (Cutter *et al*. 2004; Finan *et al.* 2002; Kelly & Adger, 2000). For instance, researchers from social science field tend to view vulnerability as representing the set of socio-economic factors that determine people's ability to cope with stress or change (Allen, 2003), while those from climate science often view vulnerability in terms of the likelihood of occurrence and impacts of weather and climate-related events (Nicholls *et al.* 1999). These differences limit the possibility of having a universally accepted definition for and methodological approach to assessing vulnerability *(*Adger *et al.* 2004). The purpose of this section is to present a conceptual framework that may be applied to this studies consistently.

There are many different definitions of vulnerability, and it is not the purpose of this paper to review them all. For a summary of definitions of and approaches to vulnerability, the reader is directed to (Adger, 1999). Nonetheless, it is essential to stress that we can only talk meaningfully about the vulnerability *of a specified system to a specified hazard or range of hazards*. Definitions of vulnerability in the climate change related literature tend to fall into two categories, viewing vulnerability either (i) in terms of the amount of (potential) damage caused to a system by a particular climate-related event or hazard (Jones and Boer, 2003), or (ii) as a state that exists within a system before it encounters a hazard event (Allen, 2003). The former is a function of hazard, exposure, and sensitivity may be referred to as *physical* or *biophysical vulnerability*. Conversely, the view of vulnerability as a state (i.e. as a variable describing the internal state of a system) has arisen from studies of the structural factors that make human societies and communities susceptible to damage from external hazards (Allen, 2003). It is termed "*social vulnerability*" (Kelly and Adger, 2000; Adger, 1999). In general, biophysical vulnerability is a function of the frequency and severity (or probability of occurrence) of a given type of hazard, while social or inherent vulnerability is not.

For the purpose of the current research, we used one of the most widely recognized definitions of vulnerability by the IPCC, where vulnerability is defined as *the degree to which a system is susceptible or unable to cope with adverse effects of climate change including climate variability and extremes* (IPCC, 2007a). In this definition, vulnerability is typically presented as a condition of three interrelated factors: exposure to impacts, sensitivity to impacts, and capacity to adapt to impacts (Gebrehiwot & Van Der Veen, 2014). Exposure is the nature and degree to which a system is exposed to significant climatic variations. In a practical sense, exposure is the extent to which a region, resource, or community experiences change. Sensitivity is the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli. The sensitivity of social systems depends on economic, political, cultural and institutional factors that allow buffering or attenuation of change. For example, social systems are more likely to be sensitive to climate change if they are highly dependent on a climate-vulnerable natural resource. Sensitivity can confound (or ameliorate) the social and economic effects of climate exposure. Adaptive capacity is the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (IPCC, 2007a). At the household level, it implies that in principle, factors contributing to household adaptive capacity have the potential to reduce climate change-induced damages and/or increase household benefits (Shah & Dulal, 2015). For example, people with low adaptive capacity may have difficulty adapting to change or taking advantage of the opportunities created by changes in the availability of ecosystem goods and services stimulated by climate change or changes in management. Literature also suggested that the integration of the three contributing factors should be used for vulnerability assessment irrespective of the differences that may exist in the levels or intensities of these three factors (Nkem *et al.* 2007).

2.3.Theoretical Framework

Despite differences in conceptualizing vulnerability, three main frameworks can be distinguished (Deressa *et al.* 2008). These include risk-hazard approach, political economy approach, and integrated approach as the three approaches to vulnerability assessment. Our interest here is to review the current literature on the approaches to analyse vulnerability to climate change in order to justify the theoretical framework and methodological approach that has been adopted for this study.

Risk-hazard approach**:** The risk-hazard approach is useful for assessing the risks to certain valued elements ('exposure units') that arise from their exposure to hazards of a particular type and magnitude (Füssel, 2007). Similarly, Adger *et al.* (2004) viewed biophysical vulnerability in terms of the amount of damage experienced by a system as a result of a hazard event.

The risk-hazard approach is more difficult to apply to people whose exposure to hazards largely depends on their behavior, as determined by socioeconomic factors. 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% reduction in yield due to climate change does not mean the same for poor farmers that it does for 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 sale of some of their assets. In general, the risk-hazard 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). The vulnerability concept applied in the risk-hazard framework is characterized as '*internal biophysical vulnerability*'.

Political economy approach: This approach considers vulnerability as an interaction between hazard and social vulnerability that produces an outcome, usually measured in terms of physical or economic damage or human mortality and morbidity (Brooks *et al.* 2005). This type of vulnerability is emanated from an inherent property of a system arising from within (Adger *et al*. 2004). The approach mainly focuses on the socio-economic and political status of individuals or social groups (Füssel, 2007). 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 hazard event (Kelly & Adger, 2000).

This approach recognizes the variation in the level of vulnerability is solely due to individual's differences in terms of education, gender, wealth, health status, and access to credit, access to information and technology, formal and informal (social) capital, political power, and so on. Thus, vulnerability is considered to be constructed by society as a result of institutional and economic changes (Kelly & Adger, 2000). In this tradition, Kelly and Adger (2000) define vulnerability as ''the state of individuals, groups or communities in terms of their ability to cope with and adapt to any external stress placed on their livelihoods and well-being. It is determined by the availability of resources and, crucially, by the entitlement of individuals and groups to call on these resources. Despite the importance of this approach in identifying the ability of a system, individuals or communities to cope with and respond to the stimulus based on their internal characteristics, it has its own limitation.

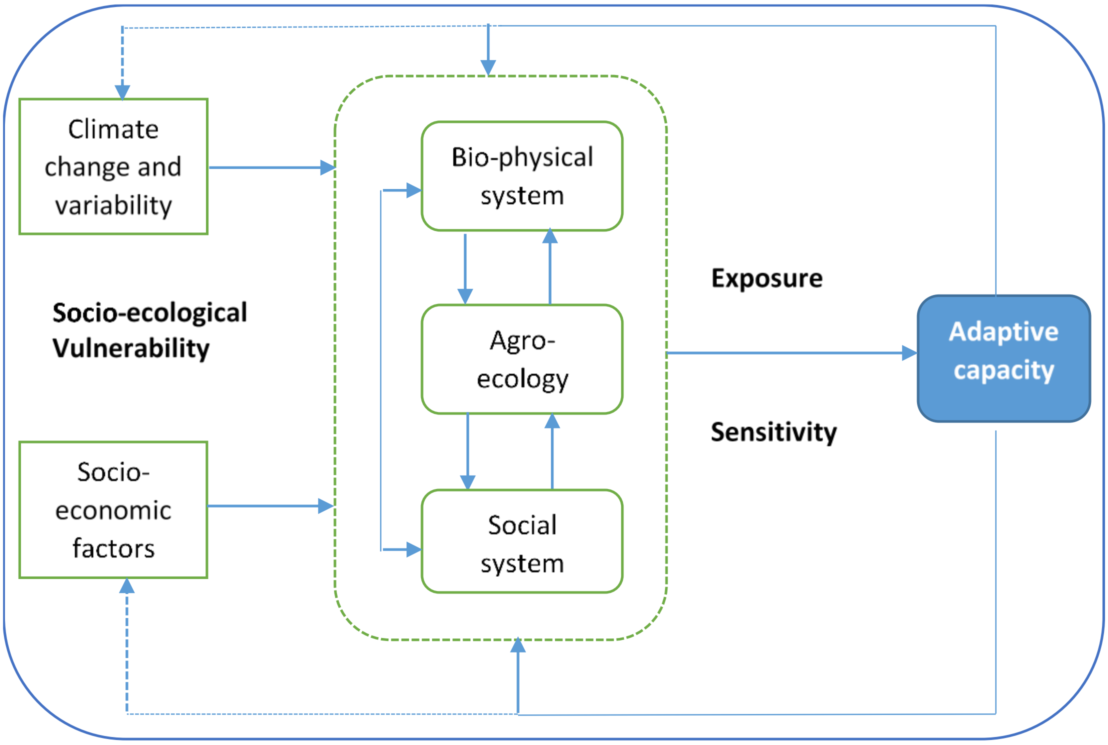
The main limitation of the political economy approach is that it focuses only on variations within society (i.e., differences among individuals or social groups). In reality, societies vary not only due to socio-political factors but also to environmental factors. Two social groups having similar socioeconomic 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 drought and flood.

Integrated approaches: Integrated approach combine risk-hazard approach and the political economy approach to determine vulnerability. One of its key features is the combination of 'internal' factors of a vulnerable system with its exposure to 'external' hazards. The literature on vulnerability viewed the hazard-of-place model and vulnerability mapping approach as a good example in which both biophysical and socio-economic factors are systematically combined to determine vulnerability (Füssel, 2007; Cutter *et al.* 2004). Füssel and Klein (2006) argued that the IPCC definition—which conceptualizes vulnerability to climate as a function of adaptive capacity, sensitivity, and exposure—accommodates the integrated approach to vulnerability analysis. According to this definition, vulnerability includes an external dimension characterized by the exposure of a system to climate variations; an internal dimension that comprises its sensitivity; and its adaptive capacity to these stressors.

Despite the combining the risk-hazard and political economy approaches to correct their weaknesses, the integrated approach 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*. (2004) explained that because this analysis provides no common metric for determining the relative importance of the social and biophysical vulnerability, nor for determining the relative importance of each individual variable, much care is required. The other weakness of this approach is that it does not account for the dynamism of vulnerability. Despite its weaknesses, however, this approach has much to offer in terms of policy decisions.

The main traditions of vulnerability and adaptation research discussed in the above approaches vary in their ability to provide useful information for these three policy contexts. The risk hazard approach is most appropriate to inform mitigation and compensation policy whereas the political economy approach is better suited to inform the design of adaptation policies. Integrated frameworks, as the most general category, are capable of providing information for all climate policy options. Thus, the current study adopted this integrated approach to analyse the vulnerability of smallholder farmers to climate change and variability.

In the light of arguments established from theoretical framework in section 2.3 above and sustainable livelihood approach presented in chapter one of this thesis, this study adopted a broad framework (i.e. socio-ecological vulnerability) which considers socio-political and biophysical processes in its arguments for vulnerability of societies or social groups. Therefore, this research attempts to examine social-economic, political, and environmental factors and extreme events that create vulnerability to climate change and variability of smallholder farmers. The framework explains the vulnerability of the socio-ecological system as a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity (Engle, 2011; Füssel, 2007; Adger, 2006).



Source: Adapted from Engle (2011); Füssel (2007); and Adger (2006)

Figure 2.1: Theoretical framework

The basic vulnerability relationships are portrayed in Figure 2.1. The interaction of environmental and social forces determine exposure and sensitivity, and various social, cultural, political and economic forces shape adaptive capacity. Exposure affects sensitivity, which means that exposure to higher frequencies and intensities of climate risk highly affects outcome (e.g., yield, income, health). Exposure is also linked to adaptive capacity. For instance, higher adaptive capacity reduces the potential damage from higher exposure. Sensitivity and adaptive capacity are also linked: Given a fixed level of exposure, the adaptive capacity influences the level of sensitivity. In other words, higher adaptive capacity (socioeconomic vulnerability) results in lower sensitivity (biophysical vulnerability) and vice versa. Therefore, sensitivity and adaptive capacity add up to total vulnerability which is called socio-ecological vulnerability (Engle, 2011; Füssel, 2007; and Adger, 2006).

2.4. Methodology

2.4.1. Methods of data collection

Both quantitative and qualitative methods of data collection were used to obtain information from the selected respondents. Quantitative data were gathered using semi-structured questionnaire. Qualitative data were obtained from FGDs and key informant interview to complement the information obtained through a semi-structured questionnaire in order to have a better understanding of major indicators that to explain the level of vulnerability to climate change and variability. Questions were posed to investigate factors that contribute to lower adaptive capacity, higher sensitivity, and higher exposure that combined could lead to higher vulnerability. The description of major components and sub-components used to collect information was indicated in chapter one of this thesis. Moreover, mean monthly temperature and precipitation for the period 1991 to 2015 were obtained from Ethiopian metrological stations found in each sampled districts.

2.4.2. Methods of data analysis

Vulnerability assessment involves a diverse set of methods used to systematically integrate and examine interactions between humans and their physical and social surroundings. Econometric and indicator approaches are two techniques commonly employed to measure vulnerability to climate change and variability (Deressa *et al*. 2009). The challenge of econometric approach is the problem of testing various econometric assumptions regarding standard errors, hypotheses and confidence intervals as well as imputing causality without making stringent assumptions. The indicator approach in measuring vulnerability of agricultural communities to climate change and variability are often combined into a composite index allowing diverse variables to be integrated. The indicator approach involves selection of indicators that a researcher considers to largely account for vulnerability (Deressa *et al*. 2009). The weakness of this approach is that there is some level of subjectivity in choosing the various indicators.

Different indices have been developed by different authors in measuring vulnerability to climate change and variability. Using the indexing and vulnerability profile method, a composite index was developed by Swain and Swain (2011). This index is, however, limited to measure vulnerability to drought only. Deressa *et al*. (2009) developed an index to measure farmers' vulnerability to droughts and floods as well as other climatic extremes such as hailstorms, by employing the "vulnerability as expected poverty" approach. This approach is based on estimating the probability that a given shock or set of shocks will move a household's consumption below a given minimum level (for example, the consumption poverty line) or force the consumption level to stay below the given minimum if the household's consumption is already below this level. The drawback of this approach is that, vulnerability, being captured as expected poverty, measures future and not current vulnerability. The technique measures the tendency to be poor in future as a result of climatic extremes.

An aggregate vulnerability index for determining the level of vulnerability of the farming sector to climate change and variability was developed by Gbetibouo and Ringler (2009). It involves selecting and aggregating a number of variables that together, serve as a proxy for vulnerability. The selected variables are normalized and averages are computed to give an idea of the level of vulnerability. The shortfall of this index is that it combines both macro-economic indicators, for example, share of agricultural GDP, and household level indicators, for example, farm income. The use of the aggregate vulnerability index, therefore, requires secondary data that may not be current and readily available. Macro-economic data because of its aggregate nature may not adequately reflect a particular farming community. Eriyagama et *al*. (2010) also developed an index of vulnerability to climate change. In addition to combining both macro and micro indicators, this approach only considered twelve variables to compute the index. Furthermore, they only used single variable, frequency of occurrence to climatic stress, to measure the level of exposure to climate change.

Given the limitations of the above indexes, Hahn *et al*. (2009) developed the livelihood vulnerability index (LVI) that integrates climate exposure and accounts for household adaptation practices that allows to comprehensively evaluate livelihood vulnerability resulting from climate change and variability. The LVI takes into consideration other earlier methods in estimating the differential impacts of climate change. Several variables are used to capture the level of exposure to natural disasters and climate variability, adaptation capacity of households and their sensitivity to climate change impacts (Hahn *et al*. 2009). This index is easier to compute because with the exception of precipitation and temperature data, it uses primary data from households. The LVI does not only capture the susceptibility to droughts and floods, but also takes into account the current vulnerability which is useful for current planning (Hahn *et al*. 2009).

This study employed LVI developed by Hahn *et al.* (2009) with replacements of some indicators to suit the local context in the study areas. It makes use of ten major components: soil and water, agriculture, food, asset, livelihood strategies, innovation, infrastructure, socio-demographic, social network, and natural disasters and variability. The indicators were developed based on a review of the literature and development workers consultation. Furthermore, the sub-components within the major components of the vulnerability were customized to the local context in consultation with field-level agents. Table 2.1 presents several sub-components of each major component and their hypothesised effect on vulnerability (Sattar *et al.* 2017). These sub-components are selected on the basis of their relevance of contribution to each major component. Moreover, one way ANOVA analysis was employed to see the difference of the selected sub-components across the three agro-ecological zones.

Table 2.1: Major components, sub-components and their hypothesized effect on vulnerability

Major Components	**Sub-Components**	**Hypothesized functional relationship between indicator and vulnerability**
Soil and water	Inverse of average hectare of land under SWC	A large hectare of land under SWC and irrigation reduce vulnerability, but here an inverse is considered.
	Inverse of average hectare of land under small-scale irrigation	
	Percentage of households reporting land degradation caused by climate-related extremes during the past 20 years	A higher percentage of households reporting land degradation increase vulnerability.
Agriculture	Inverse of Kilograms of total production harvested	Increased quantity of total production harvested reduce vulnerability but here an inverse is considered.
	Inverse of Percent of crop diversity	Higher crop diversity reduces vulnerability but here an inverse is considered.
	Percent of household who do not save seeds	Higher the proportion of households who do not save seeds, higher is the vulnerability
Food	Percent of household who do not save crops	Higher proportion of households who do not save crops, higher is the vulnerability
	Average number of months households trouble getting enough food (range: 0–12)	Higher food insecurity results in a higher vulnerability
Asset	Inverse of number of livestock owned in TLU	Higher livestock ownership and landholding size reduce vulnerability, but here an inverse is considered
	Inverse of average landholding	
	Percent of households who do not have access to credit	A higher proportion of households who do not have access to credit increased vulnerability
Livelihood strategies	Inverse of Percent of households worked in non-farm activity	A higher percentage of households who worked in non-farm and off-farm activity reduce vulnerability, but here an inverse is considered.
	Inverse of Percent of households worked in off-farm activities	
	Percentage of households solely dependent on agriculture as source of income	A higher percentage of households solely dependent on agriculture as a source of income increase vulnerability.
Innovation	Inverse of Percent of HH used insecticide and pesticide	A higher percentage of households used insecticide and pesticide, fertilizer, improved seeds, and practiced irrigation reduce vulnerability, but here an inverse is considered.
	Inverse of Percent of HH used fertilizer	
	Inverse of Percent of HH used improved seeds	
Infrastructure	Walking distance in hours to main road	Longer the distance, the higher is the vulnerability.
	Walking distance to school	
	Walking distance to veterinary service	
	Walking distance to market	

	Walking distance to water sources	
	Walking distance to health center	
	Inverse of Percent of HH who owned mobile phone	A higher percentage of households who used mobile phone reduce vulnerability but here an inverse is considered.
Socio-Demographic	Percent of female head households	A higher proportion of female headed household increases vulnerability.
	Percentage of households where head of the household has not attended school	A higher percentage of households has not attended school, and not owned Radio increase vulnerability.
	Percent of households do not own Radio	
	Age of the household head	Positive
	Dependency ratio	Higher dependency ratio increases vulnerability.
	Inverse of Percent of households attended agricultural training	A higher proportion of households attended training reduce vulnerability, but here an inverse is considered.
Social Networks	Percent of households that have not gone to local government for assistance	A higher proportion of households do not go to the government for assistance, borrowed money, do not help others, and receive help from others increase vulnerability.
	Percent of households borrowed money through social networks	
	Percent of households do not help others	
	Percent of households who received help from others.	
	Inverse of membership in social groups	More memberships in social groups reduce vulnerability, but here an inverse is considered.
Natural Disaster and Climate Variability	Average number of floods and drought over the past 25 years	Higher the incidence of natural disasters, higher is the vulnerability
	Percent of households that didn't receive a warning about natural disasters	The higher proportion of households does not receive warning system, the higher the vulnerability.
	Percent of households whose family members injured or died because of climate change	Higher proportion of households affected by climate change, the higher the vulnerability.
	Mean standard deviation of Monthly Avg. max. temperature (1991–2015)	Increasing temperature increase vulnerability.
	Mean std. deviation of monthly Avg. minimum temperature (1991–2015)	Increasing temperature increase vulnerability.
	Mean std. deviation of monthly Avg. Precipitation (1919-2015)	Decreasing precipitation increase vulnerability.

To calculate the LVI, we used a balanced weighted average approach where each sub-component contributes equally to the overall index through each major component which comprised different number of sub-components (Legese *et al.* 2016). No prior assumption is made about the importance of each indicator or main components in the overall sum (Sullivan *et al.* 2002). Many authors (Simane *et al.* 2016; Aryal *et al*. 2014; Etwire *et al.* 2013; Shah *et al.* 2013) have used similar approach in various contexts because this assessment tool is accessible to a diverse set of users in resource-poor settings. Minimum and maximum values were used to transform indicator into a standardized index.

As each sub-component was measured on a different scale, it is, therefore, necessary to standardize each as an index using the following equation;

$$index_{s_r} = \frac{s_r - s_{min}}{s_{max - s_{min}}} \qquad (1)$$

Where s_r is the observed sub-component indicator for agroecology r and s_{min} and s_{max} are the minimum and maximum values, respectively. The equation for standardizing numerical values is the same as that used in constructing the Human Development Index—HDI (UNDP, 2008). After all the sub-components are indexed, the sub-components had been averaged to calculate the value of each major component as shown in equation 2:

$$M_r = \frac{\sum_{i=1}^{n} index_{s_{ri}}}{n} \qquad (2)$$

where M_r is one of the ten major components [Soil and Water, Agriculture, Food, Asset, Livelihood Strategies, Innovation, Infrastructure, Socio-Demographic, Social Networks, and Natural Disasters and Climate Variability] for agroecology r; $index_{s_{ri}}$, represents the sub-components indexed by i, that make up each major component, and n is the number of sub-components in each major component. Once values for each of the ten major components for agroecology were calculated, they were averaged using Eq. (3) to obtain the agroecology-level LVI (Makondo *et al*. 2014) :

$$LVI_r = \frac{\sum_{i=1}^{10} w_{mi} M_{ri}}{\sum_{i=1}^{10} w_{Mi}} \qquad (3)$$

Where, LVI_r is the Livelihood Vulnerability Index for agroecology r, equals the weighted average of the ten major components. The weights of each major component, w_{Mi}, are determined by the number of sub-components that make up each major component and are included to ensure that all sub-components contribute equally to the overall LVI (Sattar *et al.* 2017; Sullivan *et al.* 2002). In this paper, the LVI is scaled from 0 (least vulnerable) to 0.5 (most vulnerable) (Sattar *et al*. 2017).

Following from equations (1)–(3), Hahn *et al.* (2009) calculated a new variable, LVI–IPCC by taking IPCC definition of vulnerability into consideration. The LVI–IPCC diverges from the LVI when the major components are combined (Sattar *et al.* 2017). Rather than merging the major components into the LVI in equation (3), the major components are first combined according to three categories namely exposure, adaptive capacity and sensitivity using the following equation:

$$CF_r = \frac{\sum_{i=1}^{n} w_{mi\,M_{ri}}}{\sum_{i=1}^{n} w_{Mi}} \qquad (4)$$

Where CF_r is an IPCC-defined contributing factor (exposure, sensitivity, or adaptive capacity) for agroecology r, M_{ri} is the major components for agroecology r indexed by i, w_{Mi} is the weight of each major component, and n is the number of major components in each contributing factor. Once exposure, sensitivity, and adaptive capacity were calculated, the three contributing factors were combined using equation 5:

$$LVI - IPCC_r = (e_r - a_r)^{*} s_r \qquad (5)$$

Where $LVI - IPCC_r$ is the LVI for agroecology r expressed using the IPCC vulnerability framework, e_r is the calculated exposure score for agroecology r (equivalent to the natural disaster and climate variability major component), a_r is the calculated adaptive capacity score for agroecology r (weighted average of the Assets, livelihood strategies, Innovations, Infrastructures, socio-demographic, and social networks), and s_r is the calculated sensitivity score for agroecology r (weighted average of the Soil and Water, Agriculture, and Food). The LVI-IPCC was scaled from -1 least vulnerable) to 1 -most vulnerable (Legese *et al*. 2016).

Finally, this research was framed in the lens of vulnerability framework developed by Turner and his colleague's (Turner II *et al*. 2003) based on the IPCC definition to understand farmer vulnerability. Turner and his friends divided a system's vulnerability into three major components: exposure, sensitivity, and adaptive capacity. Exposure considers the frequency, magnitude, and duration to which a system is subject to hazards. We used the term 'climate-related hazards' to cover both climate-related shocks, such as floods and droughts, and longer-term climate stresses, such as increasing rainfall variability and increasing temperature. The sensitivity of a system is determined by both the environmental and human characteristics that contribute to how a system responds to exposures. Finally, the adaptive capacity of a system refers to actions that can improve a system's ability to cope with outside hazards.

2.4.3. Indicators of vulnerability

Adaptive capacity, exposure, and sensitivity are the key factors that determine the vulnerability of households and communities to the impacts of climate variability and change (IPCC, 2007c). Indicators for each of these factors are, therefore, essential elements of a comprehensive vulnerability assessment.

For this study, *adaptive capacity* is represented by asset, livelihood strategies, innovation, availability of infrastructure, socio-demographic, and social networks. Asset enables communities to absorb and recover from losses more quickly due to insurance, social safety nets, and entitlement programs (Cutter *et al*. 2004). Livestock is an important component of the agriculture system. It is an asset for a family as it provides the significant energy input to the croplands required for plowing, threshing and essential nutrients required for soil fertility and crop yields in the form of organic manure. In the case of disasters or any impact on agriculture, livestock can serve as means of coping mechanism. It can be a source of alternative or additional income for the farmers. Thus, higher livestock ownership would indicate higher adaptive capacity. A number of livestock owned, a hectare of land owned, and available finance is commonly used as indicators of asset in rural African communities (Kurukulasuriya & Mendelsohn, 2006). Thus, we assumed that households and communities with more of these are better able to cope with and adapt to the impacts of climate variability and change.

Access to agricultural inputs is identified as an indicator of innovation. For instance, Deressa *et al*. (2008) noted that 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.

Deressa *et al.* (2008) pointed out that 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, access to health services are an important indicator of adaptive capacity in case of disasters and other related health impacts. Similarly, access to educational services facilitate adaptation to climate change. Microfinance plays a vital role by providing credits for technology packages that would help increase the adaptive capacity (Deressa *et al*. 2008). Smith & Lenhart (1996) indicated that countries with well-developed social institutions are considered to have 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.

The literacy rate is another important factor contributing to adaptation to climate change. It shows the degree to which the community can have access to the right kind of knowledge in understanding changes in the environment and the management practices required to deal with them. Smith & Lenhart (1996) argued that communities with higher levels of stores of human knowledge are considered to have greater adaptive capacity than those do not.

Sensitivity is the degree to which a system is affected, either adversely or beneficially, by climate change stimuli (IPCC, 2007c). In this study, three indicators were considered that may have an influence on the sensitivity of the farming community in the study area. These includes: soil and water, agriculture and food. Thus, it is hypothesised that smaller area covered under SWC, irrigation, and higher perception of land degradation increases sensitivity of smallholder farmers' to climate change and variability. In addition, smaller amount of total production harvested, less crop diversity, and larger households who do not save seed increase sensitivity. On the same vein, high prevalence of food insecurity has a positive impact on sensitivity to climate change and variability.

E*xposure* is the nature and degree to which a system is exposed to climate variations (IPCC, 2007c). Temperature and precipitation are critical parameter of climate which strongly influence people, biodiversity, and ecosystems. It governs the distribution and abundance patterns of both plant and animal species. It is generally agreed that increasing temperature and decreasing precipitation are both damaging to the already hot and water scarce agriculture (Deressa *et al*. 2008). Exposure indicators selected for this study characterize the frequency of extreme events, a warning system for natural disasters, number of people injured due to climate change impact, and variations in temperature and rainfall over a period of time . Thus, reduced precipitation and increased temperature in a sub-basin show a higher level of exposure to climate change.

2.5. Results and Discussions

The results of vulnerability analysis for all the three agro-ecological zones are reported in two parts. First, the results obtained from the assessment of major components and sub-components contributions to each major components for each agroecology are presented. Second, the estimated values for the different dimensions (exposure, sensitivity and adaptive capacity) of vulnerability index are presented. The LVI provides information on components that determine vulnerability. The LVI-IPCC indicates which of the three factors (exposure, adaptive capacity and sensitivity) influences the most when determining vulnerability.

2.5.1. Livelihood vulnerability index results

Table 2.2 presents LVI results and the ten major components considered in the analysis. Overall, *Kolla* agroecology has a higher LVI than *Woyina Dega* and *Dega* (0.5991; 0.5118; 0.4801, respectively), indicating relatively highly vulnerable to climate change and variability impacts. The results further show that *Kolla* agroecology is more vulnerable in terms of asset, livelihood strategies, innovation, infrastructure, socio-demographic, social network, agriculture, food, and natural disasters and climate variability; whereas *Woyina Dega* is more vulnerable in terms of soil and water component. The next sections present the details of sub-components and major components that could contribute to exposure, sensitivity and adaptive capacity for each agroecology.

Table 2.2 Major component value of vulnerability across agro-ecological zones

Contributing factors	Major component	*Kolla*	*Woyina Dega*	*Dega*
Adaptive capacity	Asset	0.7706	0.4322	0.7368
	Livelihood strategies	0.8998	0.7978	0.7640
	Innovation	0.7885	0.7255	0.6697
	Infrastructure	0.3382	0.2789	0.2164
	Socio-Demographic	0.5669	0.4619	0.4865
	Social Networks	0.5609	0.5111	0.5177
Sensitivity	Soil and water	0.8131	0.8308	0.7258
	Agriculture	0.7078	0.6221	0.5332
	Food	0.4553	0.2246	0.0762
Exposure	Natural disasters and climate variability	0.4916	0.4695	0.3386
LVI		**0.5991**	**0.5118**	**0.4801**

2.5.2. Exposure: Natural disaster and climate variability

The natural disasters and climate variability component are made up of six sub-components. In terms of this major component, the analysis reveals that *Kolla* agroecology is found to be more vulnerable (0.4916) whereas *Dega* agroecology is found to be least vulnerable (0.3386) (Table 2.2). The results further reveal that higher vulnerability of *Kolla* agroecology in terms of natural disasters and climate variability is as a result of three contributing factors. First, the highest percent of households to report death or injury and number of severe drought and flood were reported in *Kolla* (Table 2.3). Second, monthly maximum average temperature and monthly average precipitation were also found to be a major contributing factors for higher vulnerability to this component for *Kolla*. Third, the variability in the average maximum monthly temperature and precipitation has been greater in *Kolla* agroecology. The meteorological data further shows that *Kolla* agroecology recorded more precipitations and also witnessed more variations in maximum monthly temperature. This implies that high temperature and high rainfall will cause failure to crops grown.

The two major contributing factors for a higher vulnerability to natural disasters and climate variability for *woyina Dega* are a higher percentage of the household that did not receive a warning about impending natural disaster such as drought and floods (*Woyina Dega* 59.5 percent, *Dega* 56.56 percent, *and Kolla* 44.76 percent) and mean std. deviation of monthly average minimum temperature (2.485545). A significant number of farmers in all three agroecological zones did not receive any warning about impending natural disaster such as floods or droughts, however, the problem is most prevalent in *Woyina-Dega* agroecology where about 59.5% of the sampled households reported lack of early warning information and are, therefore, unable to adequately prepare for its expected impact (Table 2.3). This result indicates that broadcasting early warning is more limited to *Kolla* and *Dega* agroecology and not available to a remote area of *Woyina-Dega* agroecology. This may imply that early warning systems and community preparedness plans may help communities to prepare for extreme weather events. It is also noted that seasonal weather forecasts distributed through local farming associations may help farmers adjust the time for their plantings and facilitate the use of supplementary irrigation during severe drought where rainfall is insufficient.

2.5.3. Sensitivity: Soil and water, agriculture, and food

Land degradation has become one of the most important environmental problems in the Muger sub-basin, mainly due to soil erosion and nutrient depletion. Although the result does not show significant difference in the soil and water vulnerability across the three agro-ecological zones, the vulnerability of soil and water component was lowest in *Dega* (0.7258) and highest in *Woyina Dega* (0.8308). The majority of the households in *Woyina Dega* (67.5%) and *Kolla* (60.83%) reported that their land has been degraded due to climatic events, such as flash floods, landslides, and erosions (Table 2.3). Lack of efficient agricultural practice to preserve topsoil, lack of proper terrace system for farming and practice of occasional slash and burn has made topsoil prone to degradation which potentially would make households in *Woyina Dega* more vulnerable. These facts provide enough reasons to make a claim that the households in *Woyina Dega* are highly vulnerable in terms of soil and water component. One way ANOVA analysis reveals that farm size under soil and water conservation measures is significantly different across the three agro-ecological zones (Table 2.4). Households' in *Woyina Dega* constructed soil and water conservation measures such as stone bunds, soil bunds, hillside terracing, and check dams relatively on small land size as compared to households in the rest of two agro-ecological zones (Table 2.3).

Table 2.3: Sub-component index across agro-ecological zones

		Agro-Ecology	*Kolla*	*Woyina Dega*	*Dega*
Major components	Sub-component	Explanation of sub-components	Index	Index	Index
Soil and Water	Average hectare of land under SWC	Inverse of Average hectare of land under SWC	0.8422	0.8699	0.8419
	Average hectare of land under Irrigation	Inverse of Average Ha of land under Irrigation	0.9888	0.9476	0.8809
	Percent of households reporting land degradation by climate-related extremes during the past 25 years	Percentage of households reporting land degradation by climate-related extremes during the past 20 years.	0.6084	0.675	0.4545
Agriculture	Total production harvested in Kilogram	Inverse of Kilograms of total production harvested	0.9339	0.8168	0.8018
	Crop diversity	Inverse of Percent of sown area under all crops divided by number of total crops	0.6721	0.6546	0.7069
	Percent of household who do not save seeds	Percent of household who do not save seeds	0.5175	0.395	0.091
Food	Percent of household who do not save crops	Percent of household who do not save crops	0.6573	0.345	0.0708
	Number of months households trouble to get enough food	Average number of months households trouble getting enough food (range: 0–12)	0.2532	0.1041	0.0816
Asset	Number of livestock in TLU	Inverse of average number of livestock	0.8876	0.2357	0.7565
	Average hectare of land holding	Inverse of average hectare of land holding	0.8577	0.266	0.7468
	Percent of households who do not have access to credit	Percent of households who do not have access to credit	0.5664	0.795	0.707
Livelihood Strategy	Percent of households who work in non-farm activity	Inverse of Percent of households who work in non-farm activity	0.9226	0.8772	0.7920
	Percent of households who worked in off-farm activities	Inverse of Percent of households who worked in off-farm activities	0.9167	0.8163	0.8535
	Percentage of households who solely dependent on agriculture as source of income	Percentage of households who solely dependent on agriculture as source of income	0.8602	0.70	0.6465
Innovation	Percent of HH used insecticide and pesticide	Inverse of Percent of HH used insecticide and pesticide	0.8773	0.8197	0.8684
	Percent of HH used fertilizer	Inverse of Percent of HH used fertilizer	0.5793	0.5348	0.5103
	Percent of HH used improved seeds	Inverse of Percent of HH used improved seeds	0.7688	0.8230	0.7279
Infrastructure	Distance to the main road	Walking distance in hours to main road	0.3763	0.2140	0.0953
	Distance to school	Walking distance to school	0.2176	0.1579	0.1433
	Distance to veterinary service	Walking distance to veterinary service	0.2439	0.2053	0.2154
	Distance to market	Walking distance to market	0.3130	0.2174	0.1617

	Distance to water sources	Walking distance to water sources	0.1812	0.1644	0.1040
	Distance to health center	Walking distance to health center	0.2704	0.2500	0.2296
	HH owned mobile phone	Inverse of Percent of HH owned mobile phone	0.7647	0.7435	0.5657
Socio-Demographic	Percent of female head households	Percent of female head households	0.1049	0.0850	0.2222
	Household had not attended school	Percentage of households where head of the household had not attended school	0.5804	0.5600	0.4646
	Households do not own Radio	Percent of households do not own Radio	0.6923	0.2750	0.0809
	Age of the household head	Number of years of age of the household head	0.4059	0.3482	0.4423
	Dependency ratio	Dependency ratio	0.9763	0.8934	0.9649
	Households attended agricultural training	Inverse of Percent of households attended agricultural training	0.6413	0.6098	0.7443
Social Network	Households that have not gone to local government for assistance	Percent of households that have not gone to local government for assistance	0.8811	0.8900	0.9595
	Households borrowed money through social networks	Percent of households borrowed money through social networks	0.1259	0.025	0.1818
	Households who do not help others	Percent of households who do not help others	0.6434	0.9050	0.6566
	Households who received help from others	Percent of households who received help from others	0.3566	0.0600	0.1717
	Membership in social groups	Inverse of membership in social groups	0.7974	0.6753	0.6189
Natural Disaster and Climate Variability	Number of floods and drought over the past 20 years	Average number of floods and drought over the past 20 years	0.468	0.412	0.288
	Households that didn't receive a warning about natural disasters	Percent of households that didn't receive a warning about natural disasters	0.4476	0.595	0.5656
	Households whose family members injured or died because of climate change	Percent of households whose family members injured or died because of climate change	0.4663	0.035	0.0101
		Mean standard deviation of monthly Avg. max. temperature (1991–2015)	0.5608	0.4596	0.3967
		Mean std. deviation of monthly Avg. minimum temperature (1991–2015)	0.2953	0.7092	0.2597
		Mean std. dev. of monthly Avg. Precipitation (1919-2015)	0.7113	0.6059	0.5115

On the same vein, one way ANOVA analysis shows that farm size under small-scale irrigation is significantly different among the three agro-ecological zones (Table 2.4). The *Kolla* households have practiced small-scale irrigation on small size of land (0.0227 ha) next to *woyina Dega* (0.1105 ha) that contributed for higher sensitivity. *Dega* household has practiced small-scale irrigation relatively on large size of land (0.27 ha) that helps to reduce sensitivity. The small size of irrigated area out of the total sown area in *Kolla* agroecology gives an indication of the higher dependence of agricultural production on rainfall in this area. It is apparent that a small area under irrigation will increase dependence on rain-fed agriculture which is becoming more unpredictable with the advent of environmental climate change.

Table 2.4: Continuous variables considered in the ANOVA analysis

Variables	F-test	Significance level
Hectare of land under small-scale irrigation	63.209***	0.000
Crop diversity index	2.710*	0.068
Hectare of land with soil and water conservation measure	2.532*	0.081

***, **,*significant at 1%, 5%, and 10% probability level, respectively.

As seen in Table 2.2 above, agriculture component largely contributed to vulnerability of households in *Kolla* with a value of 0.7078. In *Kolla*, a larger proportion of households (about 52 percent) reported that they do not save seeds to grow for the next season. This is probably due to the fact that households in *Kolla* harvested smaller than *Woyina Dega* and *Dega* households that could only be used for their subsistence. On the other hand, the index analysis of farmers reporting not saved seeds to grow for the next season shows that *Dega* agroecology is the least with an index value of 0.091 (Table 2.3). The result further reveals that there exists a statistically significant difference in crop diversity among the three agro-ecological zones (Table 2.4). Least crop diversity was observed in *Dega* agroecology. Relatively speaking, *Woyina Dega* has larger crop diversity than *Kolla* agroecology (Table 2.3). This result suggests that research development and promotion of new seed varieties is an important concern in *Dega* agroecology that would help to reduce sensitivity to climate change and variability.

Food is another component that has a higher effect on vulnerability in *Kolla*, with a value of 0.4553 as compared to the other two agro-ecological zones (Table 2.2). The results reveal that this high value is presumably due to the fact that *Kolla* households struggled on average about 2.53 months per year to find adequate food for their families as compared to 1.04 months in *woyina Dega* and 0.8163 month in *Dega*. The result further shows that a higher percentage of *Kolla* households (65.73%) reported that they do not store crops to eat during different time of a year as compared to *woyina Dega* (34.5%) and *Dega* (7.08%) (Table 2.3). The main lesson drawn from this point is that farmers in *Kolla* agroecology are more likely to be food insecure than the other two agro-ecological zones that in effect aggravate their vulnerability to the changing climate. This suggests that adaptation options need to be designed and promoted to reduce the adverse effect of climate change and variability in *Kolla* agroecology that give priority to food security.

2.5.4. Adaptive capacity: Asset, livelihood strategies, innovation, infrastructure, socio-demographic, and social networks

The fifth component that mainly affects the vulnerability of *Kolla* agroecology is an asset with a value of 0.7706 (Table 2.2). This higher effects is presumably due to the fact that *Kolla* agroecology has lower livestock ownership and smaller landholding as compared to *Dega* and *Woyina Dega* agro-ecological zones. One way ANOVA analysis reveals that there exists a significant difference in livestock ownership and size of landholding among the three agro-ecological zones (Table 2.4). *Kolla* households owned small landholding size (1.6592 hectare) than 2.66 hectare of landholding in *Woyina Dega* and 3.39 hectare of landholding in *Dega*. Similarly, *Kolla* households reported a smaller size of livestock ownership (3.76 TLU) as compared to 7.00 TLU in *Woyina Dega* and 9.56 TLU of livestock in *Dega* (Table 2.3). This lesson might lead the policy makers to mainstream asset building strategy and intensification in the existing development that could help to offset the negative impact of climate change and variability.

Kolla agroecology, with an index value of 0.8998 on livelihood strategy component have a higher effect on vulnerability, than in *Dega* and *Woyina Dega* (Table 2.2). This value came as a result of three main factors. The first is that a higher percentage of *Kolla* households reported relying solely on agriculture for income as compared to *Woyina Dega* and *Dega* households (Table 2.3). This result supports the notion that large dependence on agriculture greatly increases household vulnerability because the agricultural sector is inherently sensitive to climate change and lack of alternative livelihood options might drive farmers to become more vulnerable to this change. The second factor is that *Kolla* households have less diversified livelihood strategies which is explained by small proportion of households with members working on non-fam activities and on off-farm activities. This tells that a more diversified livelihoods had the potential to reduce vulnerability of household. For instance, quantitative analysis of this study shows a larger proportion of households (including 35.36% and 30% in

Dega and *Woyina Dega* agroecology, respectively) tend to engage in a number of livelihood activities outside of agriculture are relatively less vulnerable as compare to *Kolla* households. This could supports the notion that household with principal livelihood activity coupled with complementary livelihood strategies are less vulnerable to climate change and variability.

With an index value of 0.7885, innovation is the high influencing component on vulnerability in *Kolla* than the rest of two agro-ecological zones (Table 2.2). Differences in innovation component among agro-ecological zones were attributed primarily to differences in the use of chemical fertilizer, insecticide, and improved seed. The application of insecticides and fertilizers is low in *Kolla* probably due to low infrastructure development. The possible explanation is that lack of access to proper roads which determines transport services might constrain the use of inputs such as fertilizer, pesticides and insecticides and this may result in a decrease in agricultural yield, and it is even more difficult and expensive to transport produce to the market in this area. On the other hand, higher percentage of households in *Dega* used improved seeds as compared to *Kolla* and *Woyina Dega* households. In *Dega* agroecology, 37.3% of households used improved seeds to enhance crop production as compared to 21.5% and 30% in *Woyina Dega* and *Kolla* households, respectively (Table 2.3).

Infrastructure development is another important component that determines the level of vulnerability of smallholder farmers in the study area. The result indicates that access to major indicators of infrastructure significantly varies across agro-ecological zones at less than 1% significance level except for distance to the health center (Table 2.5). The present study indicates *Kolla* households take more time to reach the main road, school, veterinary service, market, and water point as compared to *Woyina Dega* and *Dega* households. The results in Table 2.2 confirm that *Kolla* households have higher vulnerability score (0.3382) than *Woyina Dega* and *Dega* households on the infrastructure component (0.2789**,** 0.2164, respectively). Moreover, a small proportion of households (30 percent) in *Kolla* has access to telephone service as compared to 34% and 76% in *Woyina Dega* and *Dega* households, respectively (Table 2.3).

Table 2.5: Explanatory variables considered in the ANOVA analysis for the three agro-ecology.

Variables	F-test	Sig. level
Number of total livestock in TLU	49.071***	0.000
Educational status of the household head in year	2.974*	0.052
Age of the household heads in year	7.821***	0.000
Total crops harvested in kilogram	58.179***	0.000
Sex of the household head	6.189***	0.002
The distance from home to all-weather roads	65.955***	0.000
The distance from home to the nearest school	9.383***	0.000
The distance from home to veterinary service	3.473**	0.032
The distance from home to health services	2.215	0.110
The distance from home to water source	6.840***	0.001
The distance from home to saving and credit institution	44.573***	0.000
The distance from home to market	36.996***	0.000

***,**,*significant at 1%, 5%, and 10% probability level, respectively.

The socio-demographic component has higher vulnerability effect in *Kolla* (0.5669**)** than *Dega* (0.4865) and *Woyina Dega* (0.4619) (Table 2.2). The ANOVA analysis reveals that sex of the household head and age of the household head are statistically significant (P< 1%) among the three agro-ecological zones (Table 2.5). When the socio-demographic component is reviewed by its sub-components (i.e. indicators), *Dega* households is found to be most vulnerable in terms of female-headed households, the age of the household heads, and percent of households who do not attend agricultural training. *Dega* households reported a higher proportion of female-headed households, older household heads and a larger proportion of household heads that not received any training to cope with climate extremes than the rest of two agro-ecological zones. On the other hand, *Kolla* households have been found to be more vulnerable in terms of education, ownership of Radio, and dependency ratio. The result further shows that *Kolla* agroecology has a larger proportion of household heads that do not attend school than *Woyina Dega* and *Dega* households. The dependency ratio index is also higher for *Kolla* (0.9763) than *Dega* (0.9649) and *Woyina Dega* (0.8934) (Table 2.3).

The social network is another important component that determines vulnerability of farmers in the study site. The study found that *Kolla* households have greater vulnerability on the social network component (0.5609) than *Dega* (0.5177) and *Woyina Dega* (0.5111**)** (Table 2.2). This is possibly because a higher proportion of household heads in *Kolla* agroecology borrowed money through social networks, has not helped others, and has received help from others. On the other hand, households in *Dega* have a lower index value for the inverse of a number of memberships (0.6189) of different social groups found in the area as compared to *Woyina Dega*

(0.6753) and *Kolla* (0.7974) (Table 2.3). This shows that social capital creates incentives for farmers to reduce their vulnerability to climate change through mutual help mechanism. It is also noted that development agents and supporting organizations prefer to reach out farmers through their organized groups. This suggests that although the existing social capital has helped farmers by enhancing their adaptive capacity, the benefit of social capital is still not fully realized.

2.5.5. Livelihood vulnerability index-IPCC results

Table 2.6 presents the three contributing factors to climate change vulnerability-exposure, sensitivity, and adaptive capacity that differ across the three agro-ecological zones. As is evident from the equation for IPCC_LVI, high values of exposure relative to adaptive capacity assume positive vulnerability scores while low values of exposure relative to adaptive capacity yield negative vulnerability scores. Sensitivity acts as a multiplier, such that high sensitivity in an agroecology for which exposure exceeds adaptive capacity will result in a larger positive LVI-IPCC vulnerability scores (Hahn *et al*. 2009).

Table 2.6: LVI–IPCC contributing factors across agroecology

Agro-ecology	IPCC contributing factors to vulnerability			
	Exposure	**Sensitivity**	**Adaptive capacity (*inverse*)**	**LVI-IPCC**
Kolla	0.4916	0.6842	0.36326	0.0878
Woyina Dega	0.4694	0.6009	0.40011	0.04164
Dega	0.3386	0.4912	0.43412	-0.04692

It is apparent from Table 2.6 that the index value is only negative for *Dega* agroecology, while it is positive for *Kolla* and *Woyina Dega* agro-ecological zones. This result reveals a variation in the level of exposure, sensitivity and adaptive capacity of the smallholder farmers across agroe-cological zones. The analysis illustrates that *Kolla* household's unveils higher exposure and sensitivity and lower adaptive capacity which results in higher positive LVI-IPCC vulnerability score (0.0878) as compared to *Woyina Dega*, and *Dega* households. The highest exposure and sensitivity coupled with lowest adaptive capacity in *Kolla* contributed for its higher vulnerability. The possible explanations are that households located in *Kolla* agroecology experience more socio-economic and biophysical vulnerability. This high socio-economic vulnerability is attributed to households operating on less diversified livelihoods, low access to infrastructure, small landholding, and small livestock ownership are among others. Similar studies by Ellis & Freeman (2004) found that households which diversify their livelihood activities in the form of non-farm business activities such as trade, transport, shop keeping and brick making among others are better off economically and hence less vulnerable. A large body of literature reported lack of diversified livelihood options are the main causes for high level of socio-economic vulnerability in Ethiopia, Kenya, and India (O'Brien *et al*. 2004; Opiyo *et al.* 2014; Tesso *et al.* 2012a).

On the other hand, biophysical vulnerability is exacerbated by relatively low soil fertility due to land degradation by soil erosion, diminishing water resources and increasing trends of environmental hazards like drought and floods. All these factors lead to deterioration of agroecology thereby compromising their ability to provide ecosystem services leading to farmers' vulnerability as also reported by Callo-Concha & Ewert (2014) in other studies. In practice, *Kolla* agro-ecology with small size of land under small-scale irrigation and soil and water conservation measures are found to be highly vulnerable to risks related to climate change and variability.

The result further reveals that *Dega* agroecology is least vulnerable study site owing to its lowest sensitivity and exposure and highest adaptive capacity. The higher adaptive capacity of households in *Dega* can be explained by the fact that there exists improved infrastructure and institutional services (i.e., access to credit, extension service, and market facilities), higher asset possession, diversified livelihood strategies, and higher access to innovations. It is also noted that *Dega* agroecology has successful and endured local institutions that create relationships with a common purpose and promote shared interest. From the indicators considered in the sensitivity analysis, the *Dega* agroecology is less vulnerable because of the larger size of land under small-scale irrigation and larger size of land under soil and water conservation measures.

Overall, the key observation here is even if the existing development interventions have helped farmers to reduce the adverse effect of climate change and variability, the benefit of agroecology specific interventions to reduce farmers' vulnerability are still not fully realized. In practice, this study found that *Kolla* agroecology is the most neglected area by development interventions for unjustified reasons. This suggests that development interventions should target their efforts to reduce farmers' vulnerability to climate change and variability based on agro-ecological context.

2.6. Conclusions and Policy Implications

This paper has aimed to assess differences in smallholder farmers' vulnerability to climate change among different agro-ecological zones using empirical data obtained from 442 sampled households. Though significant attention has been given to assess vulnerability at the national level, fewer papers have looked vulnerability across varying agro-ecological zones in Ethiopia. Following on LVI developed by Hahn *et al*. (2009), the research demonstrates differences in exposure, sensitivity, and adaptive capacity of farmers across three agro-ecological zones.

The results reveal that *Kolla* agroecology is found to be highly exposed and sensitive to climate stress and has the most limited adaptive capacity. Its higher sensitivity to extreme climate events is probably because of small land under small-scale irrigation, low level of crop diversity, and high level of food insecurity in the area. The result further points out that *Kolla* agroecology has limited adaptive capacity to adapt to the changing climate is due to the combined effect of limited livelihood options, underdeveloped infrastructure, low access to the most important socio-economic factors (asset ownership and landholding) and weak social cohesion. This leads to the conclusion, business as usual, a moderate climate change will disrupt the livelihoods of smallholder farmers in this agroecology. In contrary, *Dega* agro-ecology has lower exposure and sensitivity, and higher adaptive capacity as compared to the other two agro-ecological zones and this could be attributable to higher asset ownership, developed infrastructure, more diversified livelihood options, access to innovation, and relatively well-developed social networks in this agro-ecology.

Several important policy implications can be drawn from this analysis. Feasible interventions to reduce vulnerability and ameliorate the impact of climate change revolve around promoting small-scale irrigation and crop diversification that would later or sooner help to increase food security. In line with this, it is, therefore, imperative to ensure access to alternative sources of income through non-farm and off-farm activities, improving infrastructure, and increase vulnerable farmers' asset base thereby increase their adaptive capacity to withstand the vagaries of the climate variability risk. This result also suggests that more emphasis needs to be given to invest in social capital formation by involving and building good relationships with smallholder farmers who can then take care of and obtain benefits from it to reduce their vulnerability to climate change and variability. Reducing land degradation problem using soil and water conservation measures will also help to reduce the sensitivity of farmers in the sub-basin. Overall, it is imperative to give a closer attention in planning adaptation options to reduce current and future vulnerability based on agroecology and socio-economic context.

As often stated in climate change theory, vulnerability is a function of three contributing factors via adaptive capacity, sensitivity, and exposure (IPCC, 2007c). This contributing factors varies among agro-ecological zones characterised by considerable variation in both bio-physical and socio-economic factors that explained farmers' vulnerability to climate change impacts. In practice, although this analysis provides an entry point to design and promote the right adaptation options against hazards related to climate change, exploring adaptation options and its determinants remain important concern. Future research needs to identify adaptation options and investigate factors determine the adoption of adaptation options to fully realize its benefit within the context of climate change and variability.

3. DETERMINANTS OF SMALLHOLDER FARMERS' DECISION TO ADOPT ADAPTATION OPTIONS TO CLIMATE CHANGE AND VARIABILITY IN THE MUGER SUB-BASIN OF THE UPPER-BLUE-NILE BASIN

ABSTRACT

Smallholder farmers' decisions to adopt adaptation options in response to climate change and variability are influenced by socio-economic, institutional, and environmental factors, indicating that decision patterns can be very specific to a given locality. The prime objective of this research is to identify factors affecting smallholder farmers' decisions to adopt adaptation options to climate change and variability in the Muger River sub-basin of the Blue Nile basin of Ethiopia. Both quantitative and qualitative data were collected using a semi-structured questionnaire, focused group discussions, and key informant interviews from 442 sampled households. Frequency, mean, chi-square test, and one-way ANOVA were used for analysis. Furthermore, a multinomial logit model was employed to analyze the data. Results signified that small-scale irrigation, agronomic practices, livelihood diversification, and soil and water conservation measures are the dominant adaptation options that smallholder farmers used to limit the negative impact of climate change and variability in the study area. The results further revealed that adoption of small-scale irrigation as an adaptation to climate change and variability is significantly and positively influenced by access to credit, social capital, and the educational status of household heads. Greater distance to marketplace and size of farmland negatively affected the use of agronomic practices, whereas crop failure experience, and access to early warning systems have a positive influence. The results also point out that adoption of soil and water conservation measures are positively affected by access to early warning systems, greater distance to the marketplace, and larger size of cultivated land. It is also noted that livelihood diversification is negatively influenced by socio-economic factors such as education, gender of the household head, and livestock ownership. Overall, the results suggested that improved policies aimed at increasing the adoption of adaptation options to off-set the impact of climate change and variability should focus on: creating effective micro-finance institutions and effective early warning systems, increasing farmer awareness, improving infrastructure, and encouraging farmers' membership to many social groups. The results further suggested that agro-ecological and gender-based research should be promoted and increased for a more holistic understanding of farmer options.

Keywords: adoption, adaptation options, determinant, climate change.

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3.1. Introduction

Climate change is expected to have a significant adverse effects on agricultural production in Africa due to the continent's dependence on rain-fed agriculture (Kahiluoto *et al*. 2012; Below *et al*. 2010; Glantz *et al.* 2010; Bryan *et al.* 2009; Parry and Palutikof 2007). Empirical studies show that climate change and variability already place a heavy burden on smallholder farmers, and their livelihoods will be further threatened by ongoing climate change (Thornton *et al.* 2010; Stephen, 2009; Nhemachena and Hassan, 2007).

Like most African countries, Ethiopia is frequently identified as a country that is highly vulnerable to climate variability and change (Schipper, 2011; World Bank, 2010; Parry *et al.* 2007). The agriculture sector has been playing a very significant role in providing food, employment, and income to the majority of people in Ethiopia. It accounts for about 42.9% of Gross Domestic Product (GDP), 80% of employment, and 88% of export earnings (MoFED, 2013). However, climate change remains the major challenge to the development of agriculture and food security (FAO, 2007b). Despite its high contribution to the overall economy, the sector is inherently sensitive to climate-related disasters like drought and flood and is among the most vulnerable sectors to the risks and impacts of global climate change (Rosenzweig *et al*. 2013). Studies indicate that Ethiopian agriculture is characterized by a low use of external inputs and it is highly vulnerable to climate variability and change (Bewket, 2012; White, 2012; Demeke *et al*. 2011; Schipper, 2011). The impact on agriculture is manifested by increasing incidence of floods, droughts, and unpredictable rainfall (Bardsley & Wiseman, 2012; Ribot, 2010), and have resulted in food shortage and famine in the past (Gray & Mueller, 2012; Conway & Schipper, 2011; Cheung *et al.* 2008; Mersha & Boken, 2005) and they continue to pose a serious threat to Ethiopia's development (FAO, 2007b).

Because of the huge contribution of agriculture to Ethiopian's economy and its high susceptibility to climate change and climate-related extreme events-droughts and floods, it is important to study adaptation options to overcome the anticipated adverse impacts. It has been recognized that adaptation to climate change and variability is one of the policy agenda widely supported to help smallholder farmers to limit the negative effects of climate change in this sector (Reidsma *et al.* 2009; Kurukulasuriya & Mendelsohn, 2008; Stern, 2006). There are considerable evidences that climate change holds back the progress of Ethiopian agriculture (FAO, 2017b; Deressa, 2007; Kidane *et al.* 2006; NMA, 2001). However, results from these studies were exclusively focussed on modelling future impact of climate change on agricultural production and productivity and identified adaptation options. These results are an important entry point to give policy relevance information on how climate change affect biophysical systems and outlines the potential adaptation options to ameliorate the adverse impact of climate change and variability. However, an important question remains to address the driving forces that determine household's choices of adaptation options. This presents an important limitation since farmers' responses to climate change or their choice of adaptation options have been dictated by a host of environmental, institutional, and socio-economic factors.

Furthermore, studies have been undertaken to analyze the impact of climate change and factors affecting the choice of adaptation methods in mono-crop and mixed crop production system in Africa at the regional level (Wood *et al*., 2014; Hassan & Nhemachena, 2008; Kurukulasuriya & Mendelsohn, 2008; Seo & Mendelsohn, 2008). The aggregate nature of these studies, however, make it very difficult to provide insights in identifying country-specific impacts and adaptation options given the heterogeneity of countries in terms of agro-ecological features, socio-economic, institutional, and environmental factors. This has limited the contribution of adaptation options, as the adoption of adaptation options to climate variability and change are context specific. Based on the concept of 'the existing support system the country generates determine differences in adoption of adaptation options to climate hazards among country to country' in climate adaptation discourse, the implication is, therefore, the need to conducting country specific assessment.

So far, there are limited studies (Balew *et al*. 2014; Debalke 2014; Tesso *et al*. 2012b; Tazeze *et al*. 2012; Deressa *et al*. 2009) conducted specific to Ethiopia to investigate factors affecting the choice of adaptation option. Although the results provide important information, the studies are far from conclusive and the potential determinant factors that determine farmers decision to adopt adaptation options varies in different studies. Hence, there is limited scientific evidence on which to base feasible development policy interventions, while these are urgently necessary to strengthen effective adaptation options that can be implemented by smallholder farmers and help them to improve food security. Thus, an understanding of households responses to risks related to climate change and its associated variability as well as the determinants of a household decision to adopt a particular adaptation options among the available choices is timely and pivotal, particularly in the study area where it is among the vulnerable areas of the country and which is expected to be affected severely by the changing climate. This is premised on the fact that understanding significant determinants of farmer's decision to adopt adaptation options is useful to design impactful adaptation interventions in the locality. In this context, the results of the study can potentially provide an informed basis on which policy recommendations can be drawn from these insights to facilitate the adoption of adaptation options at the local level so that the adverse impact of climate change and variability on their livelihoods can be limited.

Hence, the objectives of this study are to explore adaptation options used by smallholder farmers in response to the adverse effects of climate change and variability and to analyze factors that influence smallholder farmers' decisions to adopt adaptation options in the Muger sub-basin of the upper Blue-Nile basin.

3.2. Definitions of Concepts

While the term adaptation is widely circulated, it has no single definition of universal application. Different climate change literature defines adaptation differently. The following are some of the examples found: 1) adaptation to climate is the process through which people reduce the adverse effects of climate on their health and well-being, and take advantage of the opportunities that their climatic environment provides (Burton, 1992); 2) adaptation involves adjustments to enhance the viability of social and economic activities and to reduce their vulnerability to climate, including its current variability and extreme events as well as longer-term climate change (Smit, 1993); 3) the term adaptation means any adjustment, whether passive, reactive or anticipatory, that is proposed as a means for ameliorating the anticipated adverse consequences associated with climate change (Stakhiv, 1993); 4) adaptation to climate change includes all adjustments in behaviour or economic structure that reduce the vulnerability of society to changes in the climate system (Smith *et al*. 1996). Recently, IPCC defines adaptation as '*adjustments in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities*'(IPCC, 2014).

These definitions have much in common. They all refer to adjustments in a system in response to climate stimuli, but they also indicate differences in scope, application and interpretation of the term adaptation. They answer the question '*'adaptation to what?*'' in different ways. For instance, it can be to climate change, to change and variability, it can be in response to adverse effects or vulnerability, and it can be in response to past, actual or anticipated conditions, changes, or opportunities. It is also noted that there are differences in how these definitions address the question '*'what or who adapt*?''. It can be people, social and economic sectors and activities, managed or unmanaged natural ecological system or practices, process or structures of systems (Smit *et al.* 2000). Moreover, these definitions spell out the ways in which forms and types of adaptations distinguished. Accordingly, adaptation can be passive, reactive or anticipatory; and spontaneous or planned (Smit *et al.* 2000). Overall, the question 'what is adaptation' is circumscribed by the system of interest (*who or what adapts*), the climate related stimulus (*adaptation to what*), and the process and forms involved (*how adaptation occurs).* The current study used IPCC definition of adaptation to critically understand farmers' responses to climate change and variability and constraining or facilitating factors that determine their decision to use the adaptation options that they think help to reduce the adverse effects arising from the changing climate and its associated variabilities.

Adaptation is an important component of climate change impact and vulnerability assessment and is one of the policy options in response to climate change impacts (Smit *et al*. 1999; Fankhauser, 1996). According to the IPCC fifth assessment report, adaptation "has the potential to reduce adverse impacts of climate change and to enhance beneficial impacts, but will incur costs and will not prevent all damages." Furthermore, it is argued that human and natural systems will, to some extent, adapt autonomously and that planned adaptation can supplement autonomous adaptation. However, "options and incentives are greater for adaptation of human systems than for adaptation to protect natural systems" (IPCC, 2014). On the same vein, within the United Nations Framework Convention on Climate Change (UNFCCC), there exists recognition of the need to adapt to climate change and to assist those countries that are least able to adapt. For instance, Article 4.1b of the (UNFCCC, 1992) stated that parties are committed to formulate, implement, publish and regularly update national and, where appropriate, regional programmes containing measures to facilitate adequate adaptation to climate change ; and cooperate in preparing for adaptation to the impacts of climate change; develop and elaborate appropriate and integrated plans for coastal zone management, water resources and agriculture, and for the protection and rehabilitation of areas, particularly in Africa, affected by drought and desertification, as well as floods (Art. 4.1 (e)). The Kyoto Protocol (Article 10) further commits parties to promote and facilitate adaptation and deploy adaptation technologies to address climate change (UNFCCC, 1998). Ethiopia, like many other countries, recognizes adaptation as an important component of its climate change response strategy and is exploring adaptation options in several sectors.

There are different ways to classify adaptation options. Agricultural adaptation options are grouped according to four main categories that are not mutually exclusive: (1) technological developments, (2) government programs and insurance, (3) farm production practices, and (4) farm financial management. In addition to the ones made above, other adaptation distinctions are discussed in a paper by Smit *et al*. (2000). A useful distinction that is often made is the one between planned and autonomous adaptation (Carter *et al*. 1994). Planned adaptation is the result of a deliberate policy decision that is based on an awareness that conditions have changed or are about to change and that action is required to return to, maintain or achieve the desired state. Autonomous adaptation involves the changes that natural and most human systems will undergo in response to changing conditions, irrespective of any policy plan or decision. Instead, autonomous adaptation will be triggered by market or welfare changes induced by climate change. Autonomous adaptation in human systems would, therefore, be in the actor's rational self-interest, whilst the focus of planned adaptation is on collective needs (Leary, 1999).

3.3. Theoretical Framework: Sustainable Livelihood Framework

This study is about an understanding of farmers' adaptation options. Its major aims are to explore farmers' decisions to use adaptation options and to identify the determinants of their decisions. The literature on climate change adaptation argued that adaptation is a complex, multidimensional, and multiscale process (Bryant *et al.* 2000). The sustainable livelihoods framework arose as a holistic tool that promotes multi-dimensional understanding of the nature and dynamics of livelihood vulnerability and adaptation. This research used sustainable livelihood perspective to draw lessons from livelihood responses and vulnerability of agricultural households in Muger sub-basin of the upper Blue-Nile basin. Sustainable livelihood literature help to shed light on livelihood responses, in the case of this study adaptation options, and vulnerability of agricultural households to climate variability and other stressors, and their implications for adapting to climate change (Adger, 2006).

In this context, the sustainable livelihoods framework is based on an understanding of adaptation options that are used as people's livelihood strategies. The literature on sustainable livelihoods demonstrates that livelihoods are composed of a combination of assets (or capitals) that allow people to follow a combination of adaptation options to attain livelihood outcomes (including better or worse food security) (Carney *et al*. 1999; Scoones, 1998). There are a number of ways in which the sustainable livelihoods framework may be used in climate change adaptation analyses. First, the framework provides insights on how people use a range of livelihood assets (natural, social, financial, human capitals) to devise adaptation options within the goal of achieving positive livelihood outcome-increased food security and reduced vulnerability (Moser *et al*. 2001). Second, the framework provides the basis for understanding how adaptation options can build adaptive capacity to enable people to better cope with change, and diversify their activities to increase resilience to unforeseen future change. The framework, for example, helps explain how farmers adapt to shocks, seasonality and economic or resource trends, and how their vulnerability may be reduced, for example through building social capital, increasing the flow of information about new technologies or by improving access rights to alternative grazing areas during drought (Adger, 2003; Kelly and Adger, 2000).

Third, it relaxes the horizon of understanding on how people's adaptation options are shaped by institutions, organizations, policies, and legislation. Sustainable livelihood literature traces the constraints in the use of adaptation options to institutions, power, inequality and other social factors (Adger, 2006). Carney (1998) argues that community and household assets such as financial capital; social capital, physical capital and natural capital are influenced by the institutions and organizations through types of policies and legislation that shape adaptation options of people. The framework further explains on how the ability to pursue different adaptation options is dependent on how human capital such as skills, knowledge and good health; social capital such as membership to more formal social groups; ownership of natural resources such as land and forest; availability of physical assets such as basic infrastructures e.g. roads; and financial capital such as credit facilities enable people to pursue different adaptation options to mollify vulnerability caused by climate change and its associated risks.

3.4. Methodology

3.4.1. Methods of data collection

The research used both primary and secondary sources to obtain quantitative and qualitative data from the selected respondents. Quantitative data was gathered using semi-structured questionnaire. Qualitative data was obtained from FGDs to complement the information obtained through a semi-structured questionnaire in order to have a better understanding of adaptation options used by farmers and barriers to adopt adaptation options. Questions were also posed to investigate factors that constrain/facilitate adaptation options to change in mean temperature and rainfall over the past five years in the study area. Mean monthly temperature and precipitation from 1991 to 2015 were obtained from Ethiopian metrological station found in each sampled district.

3.4.2. Methods of data analysis

In order to analyse and present the data collected from sampled households, descriptive statistics (frequency, mean, maximum, minimum, and standard deviation), inferential tests (Chi-square test, and one way ANOVA test), and multinomial econometric model were used. Quantitative categorical types of data were analysed using frequency and chi-square test. While quantitative continuous types of variables were analysed using one-way ANOVA, minimum, maximum, mean and standard deviation. Qualitative information was organized and constructed coherently and analysed based on theoretical framework. After computing the descriptive statistics and inferential tests, a multinomial logistic regression model was used to identify determinants of household's adoption of adaptation options where the dependent variable was found to be multi-outcome. The data analysis was conducted using Statistical Package for Social Sciences (SPSS) version 20 and STATA 12.

Multinomial Logit Model Specification

Probit and logit models are the two most popular functional forms used in adoption modeling. These models have got desirable statistical properties as the probabilities are bounded between 0 and 1. Apparently, adoption models could be grouped into two broad categories based on the number of choices or options available to an economic agent (Greene, 2000). A choice decision by farmers is 'inherently a multivariate decision'. Attempting bivariate modeling excludes useful economic information contained in the interdependent and simultaneous choice decisions (Dorfman, 1996). Since farmer's decision on the use of adaptation options involve multiple responses in which the dependent variable are discrete, it is more appropriate to treat factors which are supposed to determine farmers' decision on the use of adaptation options as a multiple choice decision. Based on this argument, the appropriate econometric model would be either multinomial logit or multinomial probit regression model. Regarding estimation, both of them estimate the effect of explanatory variables on dependent variable involving multiple choices with unordered response categories (Greene, 2000). However, multinomial probit is rarely used in empirical studies due to estimation difficulty imposed by the need to solve multiple integrations related to multivariate normal distribution (Chilot, 2007). On the other hand, a multinomial logit model is selected not only because of the computational ease but also it exhibits a superior ability to predict adaptation options and picking up the differences between the adaptation options of rural households (Chan, 2005). In this study, therefore, a multinomial logit model was employed. This model makes it possible to analyze factors influencing households' choices of adaptation options in the context of multiple choices.

The decision of whether to use any adaptation option or not could fall under the general framework of utility maximization (Komba & Muchapondwa, 2012). Following Greene (2000), suppose for the i^{th} respondent faced with j choices, we specify the utility choice j as:

$U_{ij} = Z_{ij}\ \beta + \varepsilon_{ij}$ .... ………………………………. (1)

If the respondent makes choice j in particular, then we assume that U_{ij} is the maximum among the j utilities. So the statistical model is derived by the probability that choice j is made, which is:

Prob ($U_{ij} > U_{ik}$) for all other $K \neq j$ ……………………………………… (2)

Where, U_{ij} is the utility to the i^{th} respondent from adaptation option j

U_{ik} the utility to the i^{th} respondent from adaptation option k

If the household maximizes its utility defined over income realizations, then the household's choice is simply an optimal allocation of its asset endowment to choose adaptation option that maximizes its utility (Brown *et al.* 2006). Thus, the i^{th} household's decision can, therefore, be modeled as maximizing the expected utility by choosing the j^{th} adaptation option among J discrete adaptation options, i.e.

$\max_j = E(U_{ij}) = f_j(x_i) + \varepsilon_{ij};\ j = 0...J$ ……………………………………… (3)

In general, for an outcome variable with J categories, let the j^{th} adaptation option that the i^{th} household chooses to maximize its utility could take the value 1, if the i^{th} household chooses j^{th} adaptation option and 0, otherwise. The probability that a household with characteristics x chooses adaptation option j, P_{ij} has modeled as:

$$P_{ij} = \frac{\exp(X_i^{'}\beta_j)}{\sum_{j=0}^{J}\exp(X_i^{'}\beta_j)},\ J=0...\ 3 \qquad (4)$$

With the requirement that $\sum_{j=0}^{J} P_{ij} = 1$ for any i

Where: P_{ij} = probability representing the i^{th} respondent's chance of falling into category j;

X = Predictors of response probabilities;

$\beta_j =$ Covariate effects specific to jth response category with the first category as the reference.

Appropriate normalization that removes an indeterminacy in the model is to assume that $\beta_1 = 0$ (this arise because probabilities sum to 1, so only J parameter vectors are needed to determine the J + 1 probabilities), (Greene, 2003) so that $\exp(X_i \beta_1) = 1$, implying that the generalized equation (4) above is equivalent to

$$\Pr(y_i = j / X_i) = P_{ij} = \frac{\exp(X_i \beta_j)}{1 + \sum_{j=1}^{J} \exp(X_i' \beta_j)}, \quad \text{for j = 0, 1, 2…J and}$$

$$\Pr(y_i = 1 / X_i) = P_{i1} = \frac{1}{1 + \sum_{j=1}^{J} \exp(X_i' \beta_j)}, \quad \ldots\ldots\ldots\ldots \text{(5)}$$

Where: y = A polytomous outcome variable with categories coded from 0… J.

Note: The probability of P_{i1} is derived from the constraint that the J probabilities sum to 1. That is, $p_{i1} = 1 - \sum p_{ij}$.

The multinomial logistic model crucially depends on the independence of irrelevant alternatives (IIA) assumption in order to obtain unbiased and consistent parameter estimates. This assumption requires the likely of the household's using a certain adaptation options need to be independent of other alternative adaptation options used by the same household's. Hausman test was used to test the validity of the IIA assumption.

Parameter estimates of multinomial logit model provide only the direction of effect of independent variables on dependent variables but estimate neither represent the actual magnitude of change nor probabilities (Tizale, 2007). Thus, the STATA version 12 was used to generate the parameter estimates (marginal effect). The marginal effects measure the expected change in the probability of a particular choice being made with respect to a unit change in an independent variable (Greene, 2000).

3.4.3. Definition of variables and hypothesis

The dependent variable in this study is the choice of an adaptation options that has been listed in Figure 3.1. The potential explanatory variables, which were hypothesized to influence farmers' use of adaptation options in response to climate variability and change. The variables considered in the analysis are often broadly classified as personal, physical, socio-economic, institutional, and climate factors (Tafa *et al*., 2009; Bekele & Drake, 2003). These variables include: 1) age of the household head, 2) gender of the household head, 3) education status, 4) family size, 5) membership in the social group, 6) access to extension service, 7) access to credit service, 8) climate warning information, 9) agro-ecology, 10) livestock ownership, 11) frequency of number of crop failed due to drought and flood, and 12) cultivated farm size. Table 3.1 presents the description, definition and unit of measurement for both dependent and independent variables.

Family size**:** the empirical adoption literature shows that *household size* has mixed impacts on farmers' adoption of agricultural technologies. Larger family size positively influence farmers to take up labor intensive adaptation measures like Soil and Water Conservation (SWC) and irrigation that demand labor which is a critical problem in a peak period of production and livestock rearing (Anley *et al*. 2007; Dolisca *et al.* 2006). Alternatively, a large family might be forced to divert part of its labor force into non-farm activities to generate more income and reduce consumption demands (Tizale, 2007). We hypothesize that SWC and small-scale irrigation are more labor intensive and hence we expect family size to have a positive influence on the adoption of such adaptation options. Similarly, this variable is expected to have a positive effect on the use of diversified livelihood options.

Age of the household head: The influence of *age* on adoption of SWC is unclear. Some studies found a positive relationship between age and conservation investment. This indicates that the likelihood of adoption of conservation practices is more among older farmers than the younger ones, perhaps due to older farmers could adopt SWC because they have more experience that helps them to perceive erosion problems (Amsalu & De Graaff, 2007; Bekele & Drake, 2003a). Conversely, older farmers could be less willing to bear the risk of investing in SWC due to their shorter planning horizons (Anley *et al.* 2007; Dolisca *et al*. 2006). In this study, we hypothesize that age of the household head has both positive and negative impacts on adaptation options. Empirical studies by Arega *et al*. (2013) and Gebreyesus (2016) showed that age of the household head negatively related to farmers decision to diversify to non-farm and off-farm activities. Thus, age is hypothesized to negatively influence the decision to diversify livelihood options.

***Gender of the household head*:** it is a dummy variable that takes 1, if the household head is male, 0, otherwise. Many previous literature on adaptation showed that the influence of gender on adoption of adaptation options are mixed. Female farmers have been found to be more likely to adopt natural resource management and conservation practices (Bayard *et al*. 2007; Dolisca *et al*. 2006). However, some studies found that male household heads had a better opportunity to take an adaptation option than female household by involving on agronomic practices (such as crop diversification and use of drought-tolerant crop species) and by adopting SWC measures and irrigation to their farm (Deresse *et al*. 2014; Asfaw & Admassie, 2004). For instance, Asfaw & Admassie (2004) noted that male-headed households are often considered to be more likely to get information about new technologies and take risky businesses than female-headed households. We hypothesize that female- and male-headed households differ significantly in their ability to adapt to climate change because of major differences between them in terms of access to assets, education and other critical services such as credit, technology and input supply.

Education: It is a continuous variable defined as the years of schooling attained by the household heads. In most of the adoption studies, it has been shown that education is an important factor that positively influences adoption decisions (Damena, 2012; Anley *et al*. 2007; Tizale, 2007; Asrat *et al*. 2004; Sidibe, 2004). These studies have shown that better education and more farming experience increases farmers' ability to get and use of information and improve awareness of potential benefits and willingness to participate in local natural resource management and conservation activities. Educated and experienced farmers are expected to have more knowledge and information about climate change and agronomic practices that they can use in response (Maddison, 2006). We expect that improved knowledge will positively influence farmers' decisions to take up adaptation options.

Farm size*:* Empirical adoption studies have found mixed effects of *farm size* on adoption of SWC. For example, a study on soil conservation measures and irrigation in Ethiopia found that farmers with large farm size were found to have more land to allocate for constructing soil bunds, stone bunds, check dams, and improved cut-off drains and motivated to use irrigation (Kassa *et al*. 2013; Amsalu & De Graaff, 2007; Asrat et al., 2004; Tadesse & Belay, 2004). Similarly, Gbetibouo (2009) revealed that farm size is positively correlated with the probability of choosing irrigation as an adaptation option. On the other hand Nyangena (2008) found that farmers with a small area of land were more likely to invest in soil conservation than those with a large area. It is also supported by the study conducted by (Deressa *et al.* 2009). According to their argument, the need for specific adaptation option (i.e. SWC measures) to climate variability and change is dictated by characteristics of the plot than the size of the farm. This means that it is not the size of the farm that determine their behaviour but rather it is the characteristics of the farm matters. Empirical studies have shown that the area of land owned by the household has a negative correlation with the likelihood of diversifying to non-farm and off-farm activities (Gebreyesus, 2016; Arega *et al.* 2013). Therefore, it is hypothesized that farm size to have a positive role in the decision to use irrigation. On the other hand, farm size was expected to negatively affect the use of different livelihood diversification options and agronomic practices.

Access to agricultural extension services*: Extension services* are an important source of information on agronomic practices as well as on climate. Extension education is found to be an important factor motivating increased intensity of use of specific SWC practices and irrigation use because access to extension services and information help farmers to have better understanding of the land degradation problem and soil conservation practices and hence may perceive SWC practices to be profitable (Anley *et al.* 2007; Tizale, 2007; Asrat *et al.* 2004; Bekele & Drake, 2003). Thus, extension service is hypothesized to influence the decision to use SWC practices, agronomic practices, and irrigation use. This study postulates that the availability of better climate and agricultural information helps farmers make comparative decisions among alternative crop management practices and hence choose the ones that enable them to cope better with changes in climate (Kandlinkar & Risbey, 2000).

Access to Credit: Several studies have shown that *access to credit* is an important determinant factor in the adoption of various technologies (Deresse *et al*, 2014; Gbetibouo, 2009; Tizale, 2007; Kandlinkar & Risbey, 2000). Deressa *et al.* (2009) and Gbetibouo (2009) reported that farmers with more financial and other resources at their disposal are able to make use of all their available information to invest on the use of irrigation, use of agricultural inputs, use of drought tolerant crop species, use of SWC, and take up livelihood diversification in response to changing climatic and other conditions. Credit provision has the advantage to solve financial constraints to meet their need and to change their practices to suit the forecasted climate change. Thus, it is hypothesized that access to credit has a positive effect on the use of irrigation, use of SWC measures, use of agronomic practices, and use of non-farm and off-farm activities.

Market access: distance to the nearest market is used as a proxy for availability of input and output markets. It is another important factor affecting adoption of agricultural technologies. The households located farther away from markets are less likely to adopt adaptation practices (Below *et al.*, 2012; Deressa *et al*. 2011; Hassan & Nhemachena, 2008; Maddison, 2006). Input markets allow farmers to acquire the inputs they need such as different seed varieties, fertilizers, and irrigation technologies. At the other end, access to output markets provides farmers with positive incentives to produce cash crops that can help improve their resource base and hence their ability to respond to changes in climate (Hassan & Nhemachena, 2008). Madison (2006) observed that long distances to markets decreased the probability of farm households to adopt adaptation in Africa. Lapar & Pandely (1999) found that in the Philippines access to markets significantly affected farmers' use of conservation technologies. Piya *et al.* (2013) showed that in Nepal, distance to markets negatively and significantly affected the use of SWC technologies. It is expected that the households located farther away from the nearest market are less likely to adopt livelihood diversification options, varietal selection, small-scale irrigation, and the construction of SWC, but more likely to depend on traditional coping strategies.

Livestock ownership in TLU: Previous studies have shown mixed evidence about the relationship between livestock ownership and farmers' decision in relation to SWC investment (Kassa *et al*. 2013; Damena, 2012; Amsalu & De Graaff, 2007; Tizale, 2007). Amsalu & De Graaff (2007) showed that livestock ownership has positive influence to adopt stone terrace. On the contrary, more specialization in livestock negatively influences the use of SWC by reducing the economic impact of soil erosion. Hence, the effect of the size of livestock holding on conservation decision is difficult to hypothesize a prior. livestock holding negatively influences household's choice of non-farm and off-farm activities That means the farmer with lower livestock holding would be obliged to diversify livelihoods into off and non-farm in order to meet their basic needs (Eshete, 2007; Lemma, 2003). Therefore, it is hypothesized to have a negative relationship with diversifying livelihood options.

Access to weather information: Smallholder farmers require different types of climate information during each stage of the agricultural production process in order to adapt to climate variability and change. Major climate change information includes early warning signals, weather forecasts, pest attacks, input management, cultivation practices, pest and disease management, and prices (Aker, 2011; IPCC, 2007b; Thornton *et al.* 2006). Nhemachena & Hassan (2007) reported that better access to weather information has a positive influence on the decision to invest in SWC measures, use of irrigation, use of drought tolerant crop varieties, and diversify livelihood options in the response to climate change problem. In the same way, Deressa *et al.* (2014) found that access to climate information increases the likelihood of using SWC measures, and different crop varieties to adapt climate change. The effect of access to weather information on the decision to use SWC measures, irrigation, drought tolerant crop varieties, and livelihood diversification is expected to be positive.

Membership in a social group: membership to social groups or organizations enables farmers to acquire information on proper agronomic practices, credits, and productive inputs as well as to attend training and workshops at which stakeholders meet and exchange ideas. Self-help grouping and formation of cooperatives are a more reliable and pragmatic means of achieving social capital and ensuring dissemination and adoption of innovative technology (Mpogole, 2013; Dikito, 2001; Coleman, 1998). Tafa *et al.* (2009) found that being a member of a social group increased the probability of adapting climate variability and change using conservation agriculture, drought-tolerant varieties, and irrigation. Thus, it is hypothesized that membership in social groups positively affects adoption of adaptation options in response to climate change impact.

Agro-ecological setting**:** In Ethiopia, *Kolla* agroecology *(lowland) is characterized by* relatively hotter and drier climate whereas *Weyina Dega* (middle land) and *Dega agroecology* (highland) are wetter and cooler (Hurni, 1998). Evidence revealed that farmers living in different agro-ecological settings have their own choice of adaptation options (Legesse *et al*. 2013; Tessema *et al*. 2013; Deressa *et al*. 2009). For instance, Deressa *et al.* (2009) observed that farming in the *Kolla* zone significantly increases the probability of using SWC practices, as compared to farming in *weyina Dega*. However, farming in *Kolla* significantly reduces the probability of using different crop varieties, planting trees, and irrigation as compared to farming in *weyna Dega*. Hence, agroecology was hypothesized to have a positive or negative effect on household's adoption decision on climate change adaptation options.

Table 3.1: Descriptions, definition, and values of variables used in empirical model

Variable	definition	Value and Unit of measure
Dependent variable		
Adaptation option	Adoption options	It is a categorical variable which takes the value 0 for not using any adaptation option, 1=using soil and water conservation measure, 2=using small-scale irrigation, 3=using agronomic practices, and 4=using different livelihood diversification strategies.
Independent variables		
Agroecology	Agroecology	It is a categorical variable takes the value 0 for *Kolla*, 1, for *woyina Dega*, and 2 for *Dega*
Sexhh	Gender of the household head	It is dummy variable takes the value 1, for male and 0, otherwise.
Agehh	Age of the household head	It is a continuous variable measured in years.
Education	Education status of the household head	It is continuous variable measured in years of schooling the household head attended
Family size	Number of family members	Refers to the number of members who are currently living within the family
Social capital	Number of social groups which a household head has a membership to	It is continuous variable measured as number of social groups that a household head is membership.
Access to extension services	Access to extension services	It is a dummy variable, which takes the value, 1 if the farm household access to extension service and, 0 otherwise
Access to credit	Access to credit services	It is a dummy variable, which takes the value 1 if the farm household access to credit and 0, otherwise
Warning system	Received a warning about the flood/drought before it happened	It is a dummy variable that takes the value 1, if the household received a warning about drought/floods before it occurred, and 0 otherwise.
Livestock ownership	Number of livestock owned by the household	It is continuous variable measured in TLU
Crop failure	Frequency of number of times crop failed over the past 25 years	It is continuous variable measured in number
Cultivated land	Hectare of land cultivated	It is continuous variable measured in Hectare
Market distance	Distance from the nearest market	It is a continuous variable measured in walking hours from home to the nearest market.

3.5. Result and Discussions

3.5.1. Adaptation options of smallholder farmers to climate change and variability

Based on data from a comprehensive survey of agricultural households across three agro-ecological zones in Muger sub-basin of the Blue-Nile basin, this section briefly summarizes farmers' adaptation options in response to climate variability and change. In this survey, farmers were asked questions about what measures and practices they have typically used in order to cope with the negative impact of climate variability and changes over the past five years. The results show that adaptation options that farmers used includes using stone bund; soil bund; check dam; terrace; small-scale irrigation; drought tolerant and/or improved crop varieties; crop diversification; on-fam activity, non-farm activity, and off-farm activity. For the purpose of this analysis, the identified adaptation strategies are combined into five categories including the 'no adaptation' category for the convenience of model analysis. In this study because of their close relation, the above four adaptation strategies (namely stone bund, soil bund, check dam and terrace) are grouped into one single component of SWC measure. Similarly, use of an on-farm activity, non-farm activity, and off-farm activity are merged together into livelihood diversification option. Moreover, use of drought tolerant crop varieties, crop diversification, and improved crop varieties have merged together and categorized as an agronomic practice. Lastly, small-scale irrigation was taken as another category.

Figure 3.1 shows that the use of SWC measures (28.7%) and small-scale irrigation (27.4%) are the two most widely used adaptation options in the study area. The use of SWC option was found to reduce soil erosion associated with short but heavy rains which are usually common in the study areas. It is also disclosed that because of the unreliable and erratic pattern of rainfall and repeated drought, farmers started using small-scale irrigation schemes over their farm.

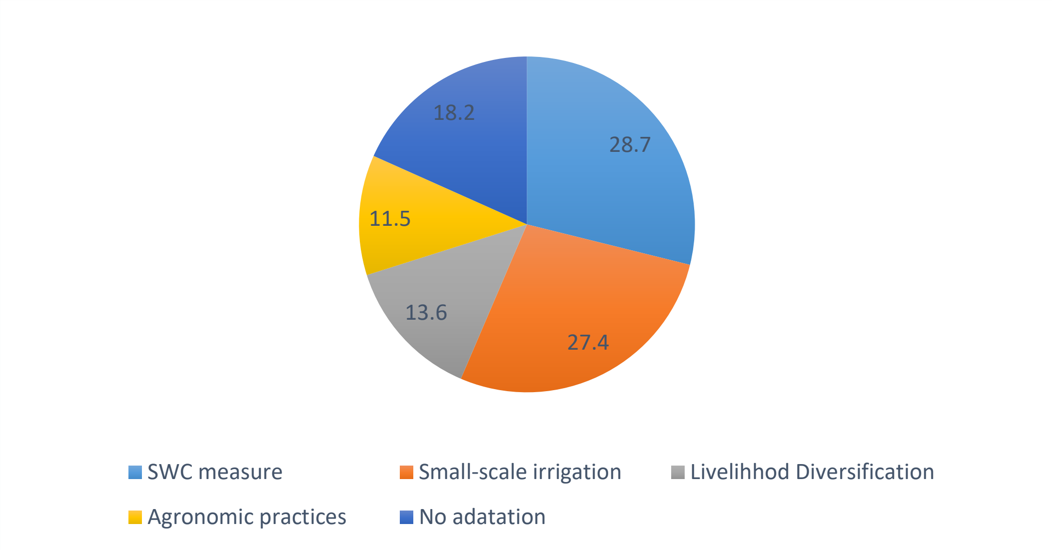

Figure 3.1: Percentage of adaptation options used by smallholder farmers

We also observed that diverted streams, pond construction and use of water pump are found to be the major means for small-scale irrigation in the Muger sub-basin. Farmers have also been using different livelihood diversification strategies as a vitally important adaptation option in the face of the uncertainties due to the implications of Climate variability and Change.

In response to effects caused by climate variability and change, smallholder farmers have been diversifying their sources of livelihood with an understanding of more diversified livelihood strategies lead them both enhance income and spread the risks for smallholder farmers. The result shows that 13.6% of the survey respondents are engaged in diversifying their livelihood strategies using off-farm and/or non-farm activities in addition to their farming practice to generate additional income. The result further indicates that agronomic practices (11.5%) is another adaptation option that is found to be used by smallholder farmers in adapting to the effects of variability and change. They used this adaptation option to overcome crop pest and diseases, and moisture stress resulted from climate change and variability. To minimize the risk from the total loss of crop production and to increase crop productivity, farmers employed diversifying crops grown on the same plot of farm, drought tolerant crop variety and improved crop variety. These strategies are important in managing current climate risks, particularly for subsistence agricultural communities of which majority are smallholder farmers. Nevertheless, the number of farmers who did not adjust their farming practices in response to climate variability and change (18.8 %) are found to be large in the study locality. However, this figure is relatively low as compared to similar data collected from Ethiopia where 37 % of farm households did not adapt (Bryan *et al*. 2009).

3.5.2. *Comparison of adopters and non-adopters of adaptation options*

Table 3.2 and 3.3 present the continuous and dummy explanatory variables that are supposed to influence adoption of adaptation options that smallholder farmers per sue in response to the adverse effect of climate variability and change. These variables are grouped into demographic characteristics, farm characteristics, and institutional factors.

Household demographic characteristics: The sampled population is made of 84.8 percent male and 15.2 percent women. This large number of men is due to the fact that men are the heads of the households and as custom demands are answerable to anyone who comes to the house. It is also reported that 99.2% of households that adopt SWC measures are found to be male-headed households, whereas 56% of non-adopters of any of the adaptation option is found to be female-headed households. The chi-square test shows that differences in gender of the household head are statistically significant (p<0.000) among the adopters and non-adopters of the adaptation options.

Table 3.2: Differences of continuous variables between adopter and non-adopter households

	Adaptation options						
Continuous Variables	No adaptation	Small-scale Irrigation	Agronomic practice	Livelihood Diversification	SWC conservation	Average Mean	Sig.
Mean of age of HH	42.72	45.1	45.14	46.38	47.28	45.46	0.138
Mean of education of the HH	1.55	4.72	2.84	2.08	3.33	3.15	0.000
Mean of family size	5.08	5.90	6.43	5.93	6.20	5.9	0.000
Mean of number of social groups	0.89	4.26	2.51	2.3	2.51	2.74	0.000
Mean of distance to market	1.88	1.30	1.5	1.42	1.96	1.64	0.000
Mean of livestock in TLU	4.92	8.54	6.17	4.77	6.51	6.5	0.000
Mean of number of times Crop failed	3.51	7.17	8.14	7.02	7.09	6.55	0.000
Mean of farm size in ha	0.98	1.84	1.15	1.21	1.89	1.47	0.000

Table 3.3: Differences of dummy explanatory variables for adopter and non-adopter households

		Adaptation options							
Dummy Variables (%)		No adaptation	Small-scale irrigation	Agronomic practices	Livelihood Diversification	SWC conservation	%	Chi-square	Sig.
Agroecology	*Kolla*	43.4	6.6	37.3	21.7	52.8	32.4	78.543	0.000
	Woyina Dega	44.6	53.7	45.1	55	33.1	45.2		
	Dega	12	39.7	17.6	23.3	14.2	22.4		
Gender of the HH	female	56	1.7	11.8	15	0.8	15.2	162.27	0.000
	male	44	98.3	88.2	85	99.2	84.8		
Extension service	no	71.1	29.8	17.6	23.3	18.9	32.1	75.307	0.000
	yes	28.9	70.2	82.4	76.7	81.1	67.9		
Credit service	no	66.3	16.5	35.3	38.3	31.5	35.3	54.563	0.000
	yes	33.7	83.5	64.7	61.7	68.5	64.7		
Early Warning system	no	65.1	16.5	45.1	23.3	15.7	29.6	78.649	0.000
	yes	34.9	83.5	54.9	76.7	84.3	70.4		

The result further shows that the mean age of sampled household heads is 45.46 years with a standard deviation of 12.67. The statistical analysis reveals that there is no significant difference in the mean age of sampled household heads between adopters and non-adopters of adaptation option. The mean family size for the sampled population is found to be 5.9 with a standard deviation of 2.021. This mean family size is above the national average family size of 4.7 persons per household (CSA, 2007). Furthermore, the mean family size for non-adopter households and adopter of agronomic practices is found to be 5.08, and 6.43, respectively. The mean difference of family size among the groups is statistically significant ($p<0.000$). Average of highest grade attained for sampled population is 3.15.The average years of formal education of adopter of small-scale irrigation and non-adopters of any adaptation option are estimated to be 4.72 and 1.5, respectively, and one way ANOVA result shows that the mean difference between non-adopters and adopters of any adaptation option is statistically significant ($p<0.000$).

Farm characteristics: The average cultivated landholding of the total sampled household heads is 1.47 hectare with an average size of 0.98 and 1.89 hectares for non-adopters and adopters of SWC measures households, respectively. The result further reveals that the mean difference between adopters and non-adopters of any of the adaptation option is found to be statistically significant ($p<0.000$). Although landholding size is significantly different between adopters and non-adopters of adaptation options, it is noted that the mean landholding of the sampled households is larger than the national average landholding of which less than 1 hectare. Livestock is an important component of the farming system in the study area. A vast majority of the sampled households included in this survey own animals of a different kind. The average livestock holding for sampled households in Tropical Livestock Unit is found to be 6.5. The average livestock holding for non-adopters and adopters of small-scale irrigation are found to be 4.92, and 8.54, respectively. One way ANOVA result reveals that livestock ownership is statistically significant at $p<0.000$ between adopter and non-adopter of any of the adaptation options.

Institutional factors: Institutional support like credit facilities, market accessibility, extension services, timely input supply, and availability of agricultural technologies, irrigation scheme, and other rural infrastructure development is central to development. The survey result indicates that from the total sampled household heads about 67.9% of households have access to extension services while the remaining 32.1% percent of sampled population do not have access to extension. The result further indicates that from the total adopters of agronomic practices, 82.4% of the households have access to extension services. On the other hand, from the total of non-adopter of any of the adaptation options, only 28.9% have access to this extension services. The chi-square analysis reveals that difference among adopters and non-adopters of different adaptation options is found to be significant at $p<0.000$ significance level. Credit availability has also a paramount importance to improve the ability of the households at critical times of year to buy inputs. Availability of credit and modern inputs is integral parts of the extension system required to increase agricultural production through the use of modern agricultural technologies like fertilizer, improved seeds, farm implements, etc. As reported from the survey result, about 64.7% of sampled households get credit either in the form of cash or in kind from government, informal local institutions, and private money lenders and from friends and relatives, while 35.3% of sampled households do not have access to credit from any credit and saving institutions. It is noticed that from a total of small-scale irrigation adopters, 83.5% of households get credit. On the other hand, only 33.7% of households that did not adopt any of the adaptation options have access to credit. It is also reported that access to credit is statistically different among adopter and non-adopter categories.

Membership in the existing local organizations was used as a proxy for social capital a farmer possesses. This social capital has the potential to internalize economic externalities and help the adoption of adaptation options in response to climate variability and change (Swinton, 2000). Table 3.2 depicts that on average farmers have a membership to 2.74 social groups. The average number of the social group that the sampled households are a membership for non-adopters and adopters of small-scale irrigation are found to be 0.89 and 4.26, respectively. The statistical analysis shows that membership to social groups is significantly different between adopters and non-adopter of any of adaptation options ($p<0.000$). Access to early warning information to climate change is another important factor determining adoption of adaptation options in response to the adverse effect of climate change. The survey result indicates that from the total sampled households, 29.6% of households get early warning information, while large proportion (70.4%) of households do not get early warning information that would have been helpful to make preparedness to reduce the adverse impact of climate change and variability. The chi-square result reveals that difference in access to early warning information is statistically significant between users and non-users of adaptation options. Although the information of early warning is broadcasted on the radio, such warning is limited to farmers who have a radio, and not available to remote areas of the study sites. Another important variable that has a strong association with the adoption of adaptation options is walking distance from the home of the household to the marketplace. A significant relationship is observed between distance to the market and adoption of adaptation options at $p<0.000$ significance level.

3.5.3. Determinants of adoption of climate change adaptation options

To estimate the multinomial logit model, we considered the first category (no adaptation) as a base category. Moreover, multicollinearity were checked using Variance Inflation Factor (VIF) and contingency coefficients (CC). The results from VIF values have shown that variance inflation factors for all variables are less than 10, which indicate all the continuous explanatory variables have no serious multicollinearity problem. Similarly, values of the CC have shown that no multicollinearity problem among dummy variables. Based on the above test, both the hypothesized continuous and dummy variables were retained in the model. Prior to running the multinomial logit model, the model was tested for the validity of the independence of the irrelevant alternatives (IIA) assumptions by using the Hausman test. The results of the tests show that the test failed to reject the null hypothesis of independence of the climate change adaptation options, suggesting that the multinomial logit (MNL) specification is appropriate to model climate change adaptation options of smallholder farmers (x^2 ranged from -2.36 to 20.37, with p-values ranging from 0.65 to 1.00). The likelihood ratio statistics as indicated by chi-square statistics are highly significant ($P < 0.01$), suggesting the model has a strong explanatory power. Table 3.4 presents the estimated coefficients of the MNL model, along with the levels of significance.

It is noted that the parameter estimates of the MNL model provide only the direction of the effect of the independent variables on the dependent (response) variable and lacks to represent the actual magnitude of change or probabilities. Thus, the marginal effects from the MNL, which measure the expected change in the probability of a particular choice being made with respect to a unit change in an independent variable, are reported and discussed. As mentioned earlier, this analysis uses the estimated coefficients of *no adaptation* as the base category and evaluates the other choices as alternatives to this option. Table 3.5 presents the marginal effects along with p-values. Multinomial logistic regression model results show that most of the explanatory variables determined adoption of adaptation options are as expected.

Gender of the household head

Agronomic practice, livelihood diversification strategies, and SWC are significantly affected by gender of the household head. It is also observed that small-scale irrigation is not influenced by gender. The results have shown that gender was negatively and significantly related to the adoption of agronomic practices and livelihood diversification strategies at 10 percent and 1 percent significance level, respectively. The results indicate that being male-headed households is more likely reduce practicing agronomic practices by 9.4 percent, and reduce to diversify their livelihood options by 16.5 percent. The negative effect of gender of the household heads on adoption of agronomic practices and livelihood diversification strategies probably due to the fact that women do much of non-agricultural works in the study area. These results are in conformity with the prior argument by Nhemachena & Hassan (2007) revealed that female-headed households are more likely to take up climate change adaptation methods. However, it is in contrary to the previous studies (Deresse *et al*. 2014; Asfaw & Admassie, 2004) showing that male headed households had better opportunity to take an adaptation measure than female household mainly due to cultural and social barriers in the area that limits women's access to land and information using agronomic practices.

Conversely, male-headed households adapt more readily to climate change using SWC. Male-headed households were about 36 percent more likely to use SWC measures. This may be explained by the fact that constructing SWC measures need substantial labor and female-headed households in Ethiopia are constrained with labor availability than male headed households. This study follows the prior argument that indicates male headed households are more likely to take up the SWC measures as compared to their counterpart's majorly because SWC structures are labor intensive (Deresse *et al*. 2014; Asfaw & Admassie, 2004). The important policy implication is the call to target women farmers and to increase their uptake of this adaptation measure.

Education status of the household head

This study shows the postive impact of education on farmers'decision to adopt small-scale irrigation, and livelihood diversification. The results further show that education has not significant influnce on use of agronomic practices and SWC measures. It is apparent that educated farmers are more likely to use small-scale irrigation which has a potential to reduce the adverse effect of exterme drought on agricultural production and productivity particularly in moisture stressed areas.

Table 3.4: Parameter estimates of the multinomial logit climate change adaptation model

	Small-scale Irrigation		**Agronomic Practices**		**Livelihood diversification**		**SWC conservation**	
Explanatory variables	Coef.	P level	Coef.	P level	Coef.	P level	Coef.	P level
Agro-ecology								
Woyina dega	0.04382	0.969	-0.81489	0.429	-0.00684	0.995	-1.94269*	0.058
Dega	-1.6309	0.260	-3.09980**	0.027	-2.06575	0.135	-4.11506***	0.003
Sexhh	4.5784***	0.001	3.39037***	0.002	2.92271***	0.007	6.31437 ***	0.000
Agehh	0.02474	0.530	.02838	0.465	0.03507	0.363	0.02153	0.571
Education	.35660***	0.002	0.15505	0.162	0.09720	0.389	0.16838	0.123
Famiy size	0.02708	0.897	0.20196	0.323	0.15449	0.444	0.06125	0.761
Social capital	3.5246***	0.000	2.62318***	0.000	2.77039***	0.000	2.79201***	0.000
Extension service	2.2494***	0.010	2.81760***	0.001	2.46013***	0.004	2.66200***	0.002
Credit service	2.3048**	0.013	1.30769	0.148	1.21670	0.173	1.29698	0.148
Distance to market	-0.3730	0.545	-0.66452	0.276	-.49368	0.418	0.06126	0.917
Early warning system	2.2758**	0.011	1.08831	0.203	2.17846**	0.012	2.47294***	0.004
Livestock	-0.06469	0.600	-0.03279	0.787	-0.22183*	0.073	-0.07275	0.547
Crop failure	0.9008***	0.000	1.00497***	0.000	0.86159***	0.000	0.84016***	0.000
Cultivated land	0.75052	0.275	-.17688	0.797	0.35875	0.600	0.80477	0.231
_cons	21.722***	0.000	-16.0392***	0.000	-15.528***	0.000	-18.4650***	0.000

Base category	No adaptation
Number of obs	442
LR chi2 (56)	642.74
Prob > chi2	0.0000
Log likelihood	-362.53853
Pseudo R2	0.4699

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

Table 3.5: Marginal effects from the multinomial logit climate change adaptation model

Adaptation options	**Irrigation**		**Agronomic Practices**		**Livelihood diversification**		**Soil and water conservation**	
Explanatory variables	Coef.	P-value	Coef.	P-value	Coef.	P-value	Coef.	P-value
Agro-ecology								
Woyina dega	0.14576***	0.002	0.00949	0.831	0.10303 **	0.013	-0.27490***	0.000
Dega	0.19773***	0.001	-0.02721	0.603	0.07924	0.154	-0.31924***	0.000
Sexhh	-0.02002	0.860	-0.09392*	0.092	-0.16525***	0.003	0.35996**	0.013
Agehh	-0.00015	0.916	0.00032	0.811	0.00117	0.397	-0.00079	0.622
Education	0.02253***	0.000	-0.00228	0.588	-0.01078**	0.027	-0.00651	0.230
Family size	-0.00904	0.284	0.01064	0.148	0.00692	0.373	-0.00600	0.514
Social capital	0.08569***	0.000	-0.01215	0.268	-0.00182	0.871	-0.01830	0.172
Access to extension	-0.03756	0.305	0.04151	0.247	0.00542	0.878	0.04077	0.345
Access to credit	0.11093***	0.002	-0.01002	0.740	-0.02863	0.370	-0.04646	0.235
Distance to market	-0.01558	0.504	-0.0387*	0.088	-0.02299	0.310	0.07019***	0.004
Early warning system	0.01877	0.639	0.0906***	0.001	0.02514	0.472	0.08395*	0.052
Livestock	0.00421	0.317	0 .0062	0.114	-0.01575***	0.001	0.00325	0.518
Crop failure	0.00366	0.644	0.0169***	0.001	0.00165	0.814	-0.00497	0.500
Cultivated land	0.02787	0.212	-0.066***	0.007	-0.01297	0.602	0.05795**	0.027

***, **,* significant at 1%, 5%, and 10% probability level, respectively.

A unit increase in a number of years of schooling would result in a 2.25% increase in the probability of small-scale irrigation to adapt to climate change. This might be education helps farmers to search and use relevant information for their farming practices. On the same vein, education helps farmers to anticipate the consequences of climate change and understand the potential benefit of small-scale irrigation to minimize the possible impact of climate change. This is possible because educated farmers are more likely consulting different agencies that promotes climate change adaptation options that would have a significant positive impact to reduce farmers' vulnerability to climate change and variability. This result supports the view of numerous studies that show the positive impact of education on farmers decision to adopt small-scale irrigation (Damena, 2012; Deressa *et al*. 2009; Anley *et al*. 2007; Tizale, 2007; Asrat *et al*. 2004; Sidibe, 2004).

A study in rural Africa shows that education is an important determining factor to engage in non-farm and skilled employment businesses (Barrett *et al*. 2001). It is more crucial that better paid local jobs require formal schooling, usually the completion of secondary school or beyond. Contrary to our expectation, level of education is negatively and significantly ($p<0.05$) determine farmers decision to adopt livelihood diversification strategies such as off and non-farm activities. A unit increase in a number of years of schooling would result in a 1.08% decrease the probability of adopting livelihood diversification strategies to climate change. This might be due to the fact that educated households may have realized higher earnings from on-farm activity than off-farm and non-farm activities that might have low return.

Social capital

It should be noted that self-help grouping and formation of cooperatives is a more reliable and pragmatic means of achieving social capital and ensuring dissemination and adoption of innovative technology (Dikito, 2001; Coleman, 1998). Membership to many social groups organized at the local level, as a proxy for social capital, is positively and significantly related to the likelihood of adoption of small-scale irrigation at 1% significance level. A unit increase in membership to the social group would result in 8.57% increase in the probability of adopting small-scale irrigation to adapt to climate change. The possible explanation of this result is that social capital increase awareness on the potential benefits of small-scale irrigation in reducing the impact of climate change on crop production. It shows a quite promising picture in which social capital is also important resource for the community in evaluating risk and vulnerability imposed by climate variability and change in such a way that it serves both to disseminate information, and to shape the way individuals process and understand that information to promote small-scale irrigation to combat the negative impact of the change on their farming.

The strong social networks can help the communities to have a strong supporting system which can enhance their adaptive capacity to respond to environmental shocks. As group discussants revealed, cooperation in the form of water user group, water shade management group, credit unions, agricultural producer organizations, livestock marketing group and women credit association have positive effects on the income-generating capacity of their members and this may capacitate farmers' financial status to invest in small-scale irrigation scheme. This result suggests that the role of individual membership to social groups in determining preference can be a useful point to consider since our result indicates that adoption of small-scale irrigation is high for those having a membership to many social groups. The result further reveals that social capital is not significantly influenced the adoption of agronomic practices, livelihood diversification, and SWC measures. Likewise, the sign of social capital on adoption of these adaptation options is not in the hypothesized direction. This is probably due to households are receiving information only limited to irrigation, but information related to different agronomic practices, different ways of creating livelihood options, and techniques of SWC are not circulated effectively by the existing social groups. The result suggests that while membership in the organization is important to receive information on adaptation options, simply membership in the organization is not sufficient for adopting different adaptation options that need skills. This further suggests a need to supplement the formation of social capital by training for capacity development.

Previous studies have shown that social capital, in its different forms, played a crucial role to adopt different adaptation options to reduce environmental shocks came out from climate variability and change (Mpogole, 2013; Deressa *et al*. 2009; Ortmun & King, 2007). For instance, Mpogole (2013) found that increased membership to social groups would increase the probability of adopting conservation agriculture, drought-tolerant varieties, and irrigation. Similarly, Ortmun & King (2007) and Mpogole (2013) found that being a member of the social networks and organizations have substantially increased the likelihood to adopt improved and high yielding varieties. On the same vein, Deressa *et al*. (2009) found that social networks increase awareness and use of climate change adaptation options.

Access to credit

Household access to credit indicates the availability of funds which is positively related to the level of adoption of adaptation options (Yirga & Hassan, 2010). Although access to credit has no significance influences on agronomic practices, livelihood diversification, and SWC measures, it has a significant influence on adoption of small-scale irrigation. As expected, the influence of access to credit service on farmer’s decision to invest in small-scale irrigation is significantly positive ($p<0.001$). Having access to credit increases the probability of adoption of small-scale irrigation by 11.1%. This may be explained by the fact that availability of credit minimizes liquidity constrains and thereby enhances adoption of small-scale irrigation. This clearly indicates that those farmers who neither have cash nor access to credit, are priced out of using small-scale irrigation. To say it in another way, adopting small-scale irrigation is heavily affected by credit market imperfections. This makes sense because the availability of credit eases cash constraints and allows farmers to purchase irrigation facilities. This suggests the important role of increased financial institutional support in promoting the use of small-scale irrigation as adaptation option to reduce the negative impact of climate change. Similar results were reported in the previous literature (Deressa *et al*. 2009; Gbetibouo, 2009; Tizale, 2007; Kandlinkar & Risbey, 2000).

Climate warning information

As hypothesized, better access to early warning about drought and flood before it happened has a significant and positive impact on the likelihood of using agronomic practices, and SWC measures on their farmland at 1% and 10% significance level, respectively. The results reveal that getting access to climate warning about drought and/or flood increases the likelihood of using agronomic practices (9%), and SWC measures (8.4%). This implies that farmers who get early warning about drought and/or flood will try to construct SWC measures such as stone bunds, soil bunds, check dams, and hillside terrace either to preserve the moisture content of the soil not to loss of water associated with increased evapotranspiration due to increased drought or to reduce soil erosion to be happened due to the flood. Moreover, early warning information helps farmers to use drought-tolerant varieties to cope with increased temperature. This result supports the findings of earlier researchers on technology adoption. Phillipo *et al*. (2015) noted that information on climate warning empowered smallholder farmers to adapt to Climate variability and change. Alike to this, a study conducted by Deressa *et al*. (2014) in assessing climate change adaptations of smallholder farmers in South Eastern Ethiopia revealed that better access to information on climate change has a significant and positive impact on the likelihood of using different crop varieties. Although it is noted that climate warning information helped increase the uptake of adaptation options, the effective early warning system remains an important concern voiced by survey respondents. This leads to the conclusion that the benefits from adaptation options may be reduced or entirely forgone if the lack of effective early warning system constrains households from adopting adaptation options.

Livestock ownership

In line with prior expectation, livestock holding in TLU negatively influences household's choice of livelihood diversification strategies at 1% probability level. This result reveals that a unit increase in a number of livestock in TLU would result in a 1.57% decrease the probability of creating another source of livelihoods like petty trading and small business as an alternative means of income. This suggests that farmers with lower livestock holding would be obliged to diversify livelihoods into off and non-farm in order to meet needs. This result is in contrary to the notion that higher livestock ownership would help farmers more likely to have better financial source helping them to create another source of livelihood (Tazeze *et al.* 2012).

Crop loss experience

Multinomial logit result shows that the number of times a household's crop failed due to the adverse impact of climate change over the last 25 years greatly influenced farmers' decision to adapt to climate change using agronomic practices. The result indicates that a unit increase in the number of times a farmer's crop failed as a result of climate change over the past 25 years could increase the likelihood of adopting agronomic practices by 1.69% at $p<0.001$ to minimize the adverse effect. This evidence suggests that farmers who have experienced crop loss due to climate-related hazards have developed their indigenous knowledge and innovations to respond to the risk. The result is in conformity with the finding of Teshager *et al.* (2014) in their investigation of determinants of adaptation strategies to climate change in the Batti district of Amhara regional state.

Agro-ecological setting

It is noted that different farmers living in different agro-ecological settings employ different adaptation options. The results reveal that farming in the *Woyina Dega,* and *Dega* agro-ecological zones significantly increases the probability of using small-scale irrigation by 14.6% and 19.8%, respectively, as compared with farming in *Kolla* zone. Similarly, farming in *Woyina Dega* significantly increases the likelihood of using different livelihood diversification strategies by 10.3%, as compared with *Kolla*. On the other hand, farming in *Woyina Dega,* and *Dega* zone significantly reduces the probability of using SWC measures by 27.5% and 31.9%, respectively, as compared with farming in *Kolla*. The results suggest that small-scale irrigation, and livelihood diversification strategies are widely considered adaptation options in both *Woyina Dega* and *Dega* agroecology to cope with the risk imposed by climate change and variability. This might be due to high irrigation potential of *Weyina Dega,* and *Dega* agro-ecology. Most of the permanent and intermittent rivers which have a potential for small-scale irrigation in the sub-basin are found in *Woyina Dega* and *Dega* agro-ecological zones. More importantly, these rivers are located in a suitable setting for using them for irrigation. Conversely, *Kolla* agroecology is endowed with less number of rivers that will be used for irrigation. It is also noted that these rivers are flowing in a gorge which needs huge capital and advanced technology to make use of them for irrigation purpose as compared to rivers found in *Woyina Dega,* and *Dega* agro-ecological zones.

Furthermore, the tendency that the household diversifies livelihoods into agriculture plus off-farm plus non-farm increases as we go from *Kolla* to *Woyina Dega*. This might be due to high infrastructure development in *Woyina Dega* zone as compared to *Kolla* zone. In a previous study, we have reported differences in access to major infrastructure across the three agro-ecological zones of this sub-basin (Amare & Simane, 2017a). This study found that households in *Kolla* agroecology had traveling an average of higher time to the main road, school, veterinary service, market, water point, and health centre as compared to *Woyina Dega* and *Dega* households. The study suggests good infrastructure development increases incentive for farmers to diversify their livelihoods that could help them reduce the negative impact of climate variability and change.

Farm size

The size of cultivated land is negatively and significantly related to the adoption of agronomic practices in response to climate variability and change in the study area. A unit increase in a hectare of cultivated land would decrease the likelihood of using different agronomic practices by 6.6%. This might be due to the fact that farmers owning large size of cultivated land have less fear to take the risk of climate change than their counterparts. Farmers with large size of cultivated land have a high probability of having many farm plots with different soil physical and chemical characteristic's that have been impacted by climate change differently. It may be this fact that relax this types of farmers not to worry about drought tolerant varieties, crop diversification, and changing planting dates to reduce impact posed by climate change and variability. This result affirms with a study done by Deressa *et al.* (2010) in the Nile Basin of Ethiopia that analyzed farmers perception of and adaptation to climate change, which supports the notion that the negative relationship between farm size and adaptation could be due to the fact that adaptation is plot specific. According to their argument, the need for specific adaptation method in response to climate variability and change is dictated by characteristics of the plot than the size of the farm.

The negative effects of farm size on adopting agronomic practices found here are inconsistent with other studies (Phillipo *et al*. 2015; Bryan *et al*. 2009; Gbetibouo, 2009). For instance, Phillipo *et al.* (2015) support the notion that households with small landholding are more likely to choose traditional crops varieties because of the associated costs to the new crop varieties. They further explained the probable reason for why small land holders do not adopt improved crop varieties, they argued that poor farmers always farm for home consumption; therefore, they are likely to choose varieties that suit them rather than the market.

The model result of this study reveals that size of cultivated land significantly increases the likelihood of using SWC measures at 5% significance level. A unit increase in a hectare of cultivated land would increase the probability of using SWC by 5.8%. The probable reason, as a matter of fact, farmers with large farm size have less risk of reduction to farm size that came out from constructing SWC measures on their farm land. The result is in conformity with the earlier studies (Kassa *et al*. 2013; Gbetibouo, 2009;Amsalu & De Graaff, 2007; Asrat *et al*. 2004; Tadesse & Belay, 2004).

Distance to the main market

It is noted that adoption of different technologies is thriving in areas with developed rural infrastructure and markets, and also where commercial agriculture prevails. As hypothesized, distance from the home of a household to the main market is found to have a significant ($p < 0.05$) negative impact on the likelihood of choosing different agronomic practices. A unit increase in walking hour from the home of a household to the main market would decrease the likelihood of using agronomic practice/s by 3.9%. The probable reason is that poor infrastructure development reduces the incentive of farmers to produce surplus production to supply to the markets using different technologies. In addition, distant farmers might have limited access to agricultural extension services; and this undermines the potential benefits of using agronomic practices to reduce the high level of production risk imposed by climate variability and change. This result suggests that improving market access for small-scale subsistence farmers would increase their ability to adapt to climate change. The result is also consistent with previous literature ((Piya *et al*. 2013; Below *et al*. 2012; Deressa *et al*. 2011; Hassan & Nhemachena, 2008).

However, contrary to what one would expect, distance to the main market is found to be positively and significantly affects the rural households' decision to invest in SWC at 1% level of significance in the study area. This may be explained by the fact that households in the remote area have less opportunity cost to adapt labor intensive adaptation practices (eg. SWC). The argument by Deressa *et al.* (2009) in favor of our finding, concurs that households in a remote area may be more willing to take up adaptation in order to reduce climate-related risk probably due to limited availability of high income earning employment opportunities in the study area. This could be further explained distant households from the main market are constrained by the lack of information and lack of access to the market to dispose of their products, have less off-farm employment opportunities, and leading to rely more on traditional strategies. Unlike our result, previous literature indicated that improving market access for small-scale subsistence farmers would increase their ability to adapt to climate change (Piya *et al.* 2013; Below *et al*. 2012; Deressa *et al*. 2011).

3.6. Conclusions and Policy Implications

It has been noted that climate change and variability adversely affects agriculture, which is the major means of livelihoods of smallholder farmers in the study area. As agriculture remains a source of income for rural communities in the study areas, adaptation to climate change and variability is imperative. It is learned that adaptation to this change tends to reduce the negative impact of climate change and variability. Different adaptation options are employed by smallholder farmers in response to climate variability and change in the study area. The main adaptation options were broadly categorized in to four categories which includes: 1) small-scale irrigation, 2) agronomic practices, 3) livelihood diversification strategies, and 4) SWC measures. It is learned that adoption of these adaptation options tends to reduce a high production risk imposed by climate variability and change. This indicates that adaptation options provide a venue to reduce sensitivity and increase the adaptive capacity of smallholder farmers that latter improve their livelihoods and ensure food security.

The study finds that better access to credit allows households to adopt small-scale irrigation. This implies that credit market imperfection can create a barrier for the capital-constrained farm households to participate in small-scale irrigation in the study area. Provision of micro-credit facilities complemented with skill development training can help the households to invest in small-scale irrigation to avert the adverse impact of climate change and variability. The study further reveals that household characteristics such as education status of the household heads which could be enhanced through policy intervention have a significant impact on adaptation to climate change using small-scale irrigation. Thus, investment in education systems which increases farmers awareness to invest in small-scale irrigation, and that help farmers to specialize on farming in the rural areas can be underlined as a policy option to reduce the negative impacts of climate change.

As often stated in climate literature, early warning system increases farmers' preparedness to design and implement adaptation options in response to the expected climate change. This improves adaptive capacity and reduces the sensitivity of smallholder farmers to the adverse effects of climate variability and change. In practice, although early warning information helped to increase the adaptive capacity and reduce the sensitivity of smallholder farmers, early warning system remains an important concern voiced by survey respondents. This leads to the conclusion that the benefits from adaptation options may be reduced or entirely forgone if concerns about early warning information constrain households from adopting adaptation options or to limit adoption of adaptation options to few smallholder farmers who have previously higher adaptive capacity and less sensitive. This implies that additional efforts to increase effective early warning system may have the desired impact on the adoption of SWC measures, and agronomic practices as adaptation options.

The results of the study also indicate the important role of social capital in adaptation to climate change. Policy interventions which encourage farmers' membership to many social groups which are known to be a venue for accessing information with the ultimate goal of increasing food security through impact of adaptation options. The result further reveals that farmers living in different agro-ecological settings used different adaptation options. Thus, the future policy has to aim at providing adaptation technologies through agroecology based research.

Experience in crop failure is another important variable that affects adoption of agronomic practices positively. With increasing experiences in crop failure, farmers adopt agronomic practices such as using improved and drought tolerant crop varieties, and using crop diversification. Thus, future policy to develop and promote improved and drought tolerant crop varieties can support farmers to better cope with climate change.

4. ASSESSMENT OF HOUSEHOLD FOOD SECURITY IN THE FACE OF CLIMATE CHANGE AND VARIABILITY IN MUGER SUB-BASIN OF THE UPPER BLUE-NILE

ABSTRACT

It is widely recognized that climate variability and frequent droughts resulting from El-Nino phenomenon are among the major risk factors affecting agricultural production that might contribute to hunger and food insecurity in East Africa in general and Ethiopia in particular. The objectives of the present study are to examine the food security status and determinants of household food security among 442 randomly selected households in the Muger sub-basin of the Blue-Nile basin using household survey, focus group discussion and key informant interview data collection methods. Descriptive statistics (mean, chi-square test, t-test), household food balance model and binary logit econometric model were used to analyze the data. The results showed that 57.8% of the households are food secured, while the remaining 42.2% of the households are food in-secured. The binary logit regression results revealed that adoption of soil and water conservation, small-scale irrigation, and employing different agronomic practices are important factors influencing household food security. Moreover, landholding size and livestock ownership positively and significantly affected household's food security. The results further showed that family size and distance to the nearest market are important factors affecting food security in the inverse direction. The results highlighted careful investments on sustainable land management practices and small-scale irrigation that reduced sensitivity and increased the adaptive capacity of smallholder farmers to the adverse effect of climate change and variability. This study further highlighted the significance of livestock ownership and landholding in attaining food security under changing climate. The finding calls to generate labour intensive and climate resilient employment opportunities that absorb the growing labor forces and invest in creating functional value-chain that help farmers' viable market for their produces.

Key words: food security, climate change, drought, determinants.

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4.1. Introduction

There is an emerging consensus that climate variability and extreme weather events are among the major risk factors affecting agricultural production and food security in Sub-Saharan Africa (Thornton & Herrero, 2014; Demeke *et al.* 2011a; Deressa *et al*. 2009; Kidane *et al*, 2006). The effect is particularly pronounced in the rural households of developing countries such as Ethiopia where the capacity to cope with the adverse effect is low (Demeke *et al*. 2011a; Falco *et al*. 2011). The dynamics of climate change also execrates other issues such as deforestation, land degradation, depletion of water resources that further complicating the challenge of food security (Jorge *et al*. 2011).

Ethiopia is particularly a vulnerable country due to its low adaptive capacity of rural households and high exposure to natural and anthropogenic threats (Conway & Schipper, 2011; World Bank, 2010; Parry *et al*. 2007). FAO (2017) reported that Ethiopia suffered tremendously from the effect of strongest El-Nino episodes ever recorded in history which plunging it into limited agricultural production, straining livelihoods, and exacerbating food insecurity among poor and vulnerable households. According to the report, the prime effect of El-Nino forced an estimated 10.2 million people to fall under food assistance in 2016 and over one-third of the country's districts facing food security and nutrition crisis (FAO, 2017).

Food security is a growing concern, particularly under imminent climate change and variability. The World Food Summit of 1996 defined food security as existing '*when all people at all times have access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life*'(FAO, 1996). There are four pillars which underpinning food security: food availability, food accessibility, food utilization, and stability (Barrett, 2010). The study by Gregory *et al.* (2005) confirms that climate change and variability potentially affect the underpinning pillars at different levels and disrupt the link between them, dwindling their ability to deliver food security.

Studies have been undertaken to measure the status of food security in Ethiopia (Abebaw *et al*. 2011; Hadleya *et al*. 2011; Zegeye & Hussien, 2011; Bogale & Shimelis, 2009; Freihiwot, 2007; Berhanu, 2004; Samuel, 2004). The studies on food security analyzed the demographic, socio-economic, and institutional factors that affect food security but failed to address the climate factors that are believed to affect food security (Demeke *et al*. 2011a). This presents an important limitation since household food security is dictated by a host of environmental factors in combination with socio-economic, and institutional factors. Moreover, a recent study that examined determinants of food security indicates the need to be context specific in identifying factors that influence specific investment in food security projects and programs (Beyene, 2014). The knowledge of these environmental factors could assists policy to enhance food security through investing on these factors and also has benefits for mainstreaming climate change issues in designing interventions that have a realistic chance of being implemented that are more likely contribute to improved food security outcomes.

Therefore, the objectives of this study are to examine the status of household food security and to analyze a host of climatic, demographic, socio-economic, and institutional factors affecting food security of farmers in the Muger-sub- basin of the upper Blue-Nile basin in Ethiopia.

4.2. Definition of Concepts

The concept of food security was coined as early as the 1970s, but the concept of household food security is more recent (Maxwell & Frankenberger, 1992). In the mid-1970s, food security was interpreted as adequacy of food supply at global and national levels. This view favoured merely food production–oriented variables and overlooked the multiple forces, which in many ways affect access to food (Maxwell & Frankenberger, 1992). The notion of equating national food security with food self-sufficiency is another problem area that should be clarified. Many countries that were considered to be self-sufficient in food were found to be food-insecure due to the fact that they either lacked an efficient food distribution/marketing system or the capacity to raise the level of food entitlement. On the contrary, some countries that face fewer food deficits were able to attain a considerable level of national food security (Maxwell & Frankenberger, 1992). These countries were able to import food through generating sufficient foreign exchange and improving the efficiency of the marketing/distribution system. Hence, in this context attaining food self-sufficiency alone does not necessarily imply the achievement of food security.

Food security is an ‘unobservable variable with complex, multi-factorial causality' (Barrett, 2002). There is a consistent general idea in the literature that the concept of food security is confusing with over 250 definitions and 400 different indicators of food security (Hoddinott, 1999). A reason for the extensiveness of definitions and indicators, as presented in literature, is due, at least in part, to the preferences and tendency of organizations and researchers. Hence, food security definitions and measurements have a considerable degree of subjectivity (Boardman, 2002).

Conventionally food security is defined as "access by all people at all times to enough food for an active and healthy life" (World Bank, 1986). It is generally accepted as entailing not only food availability (adequate supply of food) but also food access through home production, purchase in the market or food transfer. The above definition lacks the utilization and stability dimensions of food security. Recognising these dimensions, the 1996 World Food Summit (FAO, 1996a) define '*'food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life*.'' This definition conceptualized food security resting on four dimensions': availability, access, utilization, and stability.

1) *Food availability* refers to the availability of sufficient quantities of food of appropriate quality, supplied through domestic production or imports (including food aid). Although the adequate availability of food help to ensure all people to have sufficient food, adequate supplies do not ensure universal access to sufficient, safe and nutritious food (Webb *et al*. 2006). Similarly, Andersen (2009) confirmed that food availability solely does not assure access to food and enough calories do not necessarily guarantee a healthy and nutritional diet. 2) *Food access* refers to the access to adequate resources (entitlements) to acquire appropriate foods for a nutritious diet. Entitlements are defined here as the set of all commodity bundles over which a person can establish command, given the legal, political, economic and social arrangements of the community in which he or she lives, including traditional rights such as access to common resources (Sen, 1981). 3) *Food utilization* reflects concerns about whether individuals and households make good use of their accessed food to reach a state of nutritional well-being in which all physiological needs are met. 4) *Food stability* is the stability of access to adequate food at all times, independent of shocks (such as economic or climate-related crises) or cyclical patterns. This includes issues of seasonal food insecurity, such as the agricultural period before harvest known as 'the hunger season'.

This definition highlights food security is a multidimensional concept, the assessment of which requires the measurement of several indicators that can together capture the various dimensions of food security. As Webb *et al*. (2006) noted that these dimensions are inherently hierarchical, with food availability is necessary for food security but not sufficient to ensure access, which is, in turn, necessary but not sufficient for effective utilization. Meanwhile, the concept of stability cuts across the first two dimensions and can refer to variability and uncertainty in both availability and access. The existence of different dimensions' of food security calls methodological pluralism in measuring it. Literature on food security recognized a combination of measures and indicators is needed to fully reflect the complex reality of food insecurity in any given context (FIVIMS, 2002; Hoddinott, 1999).

Conversely, food insecurity is a situation in which the individuals of the society have neither the physical nor the economic access to the nourishment they need (Reutlinger, 1987). A household is said to be food insecure when its consumption falls to less than 80% of the Minimum Recommended daily Allowance (MRA) of caloric intake for an individual person to be active and healthy. On the basis of the temporal dimension, two types of household food insecurity can be distinguished: chronic and transitory food insecurity. Chronic food insecurity means that a household runs a continually high risk of inability to meet the food needs of household members. In contrast, transitory food insecurity occurs when a household faces a temporary decline in the security of its entitlement and the risk of failure to meet food needs is of short duration. Transitory food insecurity focuses on intra-and inter-annual variations in household food access (Reutlinger, 1987).

4.3. Theory of Famine and Food Security

The present paper is an attempt to contribute an assessment of food security status under changing climate. Thus, we need to see food security in the theoretical perspective. This section presents explanations of how famine occurred, through a critical integration of the academic discourse around famine causation. It examines four competing paradigms of famine causations: demographics (Neo-Malthusianism), environmental, economics (entitlement failures), and politics (complex emergencies).

Demographics (Neo-Malthusianism) Explanation**:** One of the easiest and commonest explanations of famine is population growth. This theory gets its root in Malthus's thesis- *Essay on Principle of Population, 1798* (Malthus, 1960). 'Drawing from the Reverend Thomas Malthus Essay on the principle of population (1798) who demonstrated population should not continue growing indefinitely in a world of fixed natural resources. It is argued that as land resources remain constant at best or deteriorate considerably, and as agricultural technology remain primitive, while, as a consequence of these and other adverse factors, agricultural production proceeds at a snail's pace, population growth, mainly as a result of very high birth rate, soars much faster (Mesfin, 1984). According to Malthus (1960), eventually, famine would act as a natural check on population growth, equilibrating the demand for food with food supplies.

In general terms, Malthus's thesis has been criticized and rejected on many grounds. First, viewing famine as 'natural check' on population growth control is repugnant. Secondly, Malthus failed to "foresee the 'fertility transition' to small families as a living standard rose" and the "exponential increases in agricultural productivity" owing to technological advances which "pushes production beyond the consumption needs of the global population" (Devereux, 2002).

Although it remains to be demonstrated, in the case of Ethiopia, it sounds reasonable to argue that in a subsistence production system where methods of farming remain the same for generations, while fragmentation, as well as the deterioration of farmland, get progressively worse, population pressure may become one of the factors that make farmers vulnerable to famine. Such arguments assume that the cultivable land in a given country is fully and efficiently utilized, that alternative non-agricultural economic activities cannot develop and that limiting population growth will solve the problem of poverty and famine.

None of these assumptions can be taken as valid, at the list for Ethiopia (Mesfin, 1984). And yet Malthus's line of argument is still pursued by neo-Malthusians. Despite being a very slow onset process, the argument about population exceeding natural resources has been evoked to explain rapid onset food crisis in Africa and Asia. The carrying capacity debate brought together demographers and environmentalists in a neo-Malthusian attempt to blame the persistent of famine on overgrazing in Sahelian Africa and overpopulation in South Asia (Devereux, 2002).

However, the neo-Malthusian approach is also criticized heavily. Like Malthus's crude argument, neo-Malthusians failed to take into account the role of technology in increasing food production. Moreover, 'mass mortality famines' ('natural check') does not act as population control. Rather fast population growth has been witnessed in countries which were afflicted by various famine episodes in the past (Devereux, 2002). Boserup (1965) offered a contra-Malthusian counter argument for Sub-Saharan Africa where, in her view, excessively low population densities increase vulnerability to famine by inhibiting investment in basic economic infrastructure and agricultural technologies. A statement that singles out population growth as the cause of famine in Ethiopia have absolutely no ground. For instance, it is very difficult to substantiate a statement that increases in human population is the most important single factor involved in famine in Ethiopia (Boserup, 1965).

Though Malthusian perspective is implicitly indicated in some contemporary analysis of famine, its theoretical foundation has been challenged. Firstly, technological progress has allowed an enormous increase in food production outstripping population growth. Secondly, famine has not acted as the ultimate and powerful check of population growth (Fassil, 2005). Therefore, neo-Malthusians perspective has remained inadequate to explain famine causation.

Environmental 'Supply-side' Explanations: This approach considers drought (sometimes floods) and recent climate change factors in the explanation of disruption or reduction of food output. This approach focuses on environmental limitations on food output, mainly through the drought. It looks primarily at supposed 'natural causes' which reduce the capacity of the natural resources to provide adequate food supply (Wisner *et al.* 2004). Of the major famine disasters in the past 30 years (e.g. in the Sahel zone of West Africa, in Sudan and Ethiopia and in northeast Brazil), many have been explained principally in the popular media as being caused by drought. In recent years, global climate change has emerged as an additional factor in explanations of the reduction or disruption of food output, especially in relation to drought (Downing, 1992). This approach, however, is criticized on the basis that natural events (like drought, flood and climate change) can act as triggers, rather than causing famines. Because increased risks are caused by human actions, and relate to social vulnerability and to pre-existing 'normal' level of hazards. In other words, human action is responsible for both the generation of peoples' vulnerability and the increased level of hazard (Wisner *et al*. 2004).

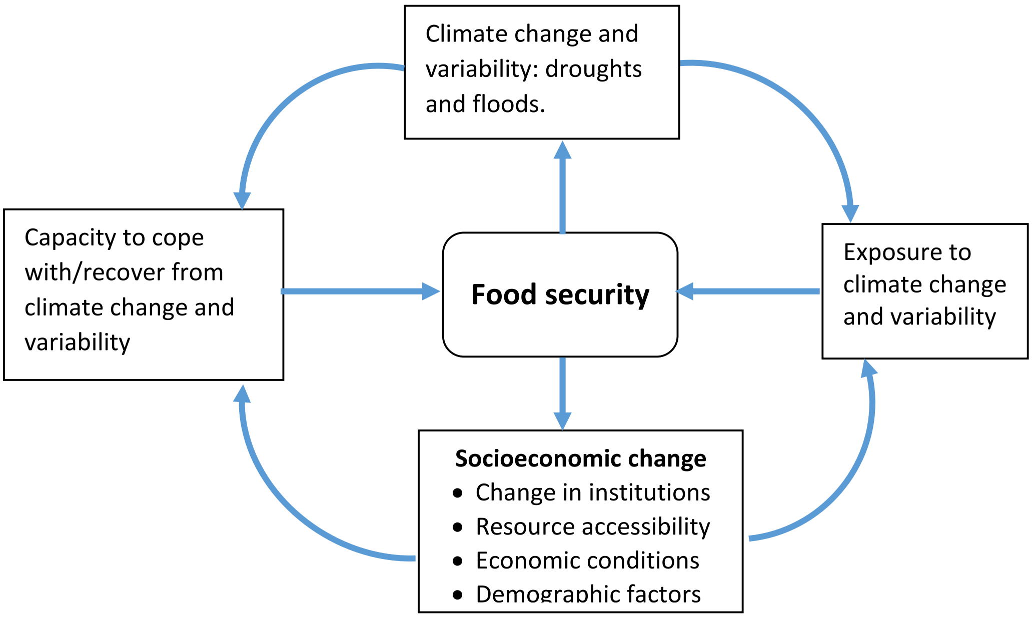
The Political Economy explanation**:** This approach emphasizes the political economy and human rights, and the emerging complexities of contemporary famines. In this regard, a number of environmental and socio-economic attributes that are assumed to explain famine such as war and civil strife, ecological degradation, government mismanagement, unequal access to resources and unequal exchange, and socioeconomic and political dislocation have been pinpointed (Devereux, 1993). The argument here is that one or a combination of these can disrupt food production. Some writers hold the ideas that despite excess food somewhere in the world, famines occur in other parts of the globe due to denial of access to food resulting from lack of political commitment. Moreover, despite much rhetoric for ensuring food security, donor nations and international organizations have channelled very limited resources for food security efforts in particular, and for development in general. A case in point is the steady decline in the flow of financial aid into Africa (Wisner *et al*. 2004; Mengisteab & Logan, 1995; Cheru, 1989). Some authors also considered famines as consequences of government action or inaction. They ascribe the responsibility for famine causation primarily to the political regime. Historical famines which were attributed mainly to failure of the political regimes of the respective countries included the Soviet famines of 1921 and 1932/33; China's Great Leap Forward famine; the 1990-91 famine in Sudan (Devereux, 2000, 2002); the 1973-74 and 1984-85 Ethiopian famines (Fassil, 2005; Devereux, 2002; Mesfin, 1984). These examples indicate that even in earlier times, famines always had political dimensions.

However, production failure may or may not result in famine. Due to this fact, the general explanations are imprecise, cannot be used in quantifying the problem, and also are not helpful in leading to accurate prediction. Hence, specific models have been developed as the second approach in the literature based on supply, demand, and market failure theories.

***Economic Explanation of Famine*:** In this economics perspective, there are two main economic explanations of famine based on different sets of causal explanations (Wisner *et al.* 2004). These are i) Food Availability Decline (FAD), and ii) Food Entitlement Decline (FED). The supply-side explanation is known as the FAD. It refers to the decline in per capita food availability. According to Devereux (1988) the central argument of this model is that "anything which disrupts food production such as drought or flood and population pressure can cause famine, the logic being that a drought or flood causes crop failure and cattle death, reducing the availability of food in the affected region and that such a food availability decline for an extended period by definition constitutes a famine". The model basically demonstrates a situation of subsistence farmers, like farmers under investigation, and reveals how a failure of production during one growing season would end up with food shortage. Nevertheless, the model is criticized for it overemphasizes food supply and undermines the demand for available food (Degefa, 2002).

The demand side explanations are known as FED model which is pioneered by Sen (1981) as an alternative method for the analysis of famine. The entitlement of a person stands for the set of different alternative commodity bundles that the person can acquire through the use of various legal channels of acquirement open to someone in his position. The central argument of FED the mere presence of sufficient food in aggregate terms does not necessarily entitle a person to access to it. This means access to food plays a crucial role in securing command over food which is, in turn, determined by production, exchange or transfer.

However, food availability and entitlement models are not independent explanations, but in fact, complement each other. Moreover, they do not address the problem at the household level. Food security at household level signifies the complementarity of the political economy explanation and the two models, due to the fact that there must be favourable and stable political situation, enough food must be available, and households must have the capacity to acquire it. Thus the framework of this study mixes the premises of the 'general explanations to famine', the two famine models and sustainable livelihood approach. The framework in Figure 4.1 depicts food security is not only determined by the nature and magnitude of climate change, but by the combination of the societal capacity to cope with and/or recover from climate change, coupled with the degree of exposure to stress. The framework also shows coping capacity and degree of exposure are influenced by changes in social aspects such as institutions and resource accessibility. Change in food security aims at reducing vulnerability feedback to climate change and variability through agricultural practices that reduce land degradation and increase agricultural productivity. Livelihoods are addressed implicitly in that food security is an outcome of livelihoods.



Adapted from Ericksen (2008)

Figure 4.1: Theoretical framework

4.4. Methodology

4.4.1. Types of data and methods of data collection

Focused Group Discussions (FGDs) and household survey were used to collect qualitative and quantitative data, respectively. Data from the FGDs' were used to complement the information obtained through a household survey in order to have a better understanding of causes of food insecurity and challenges of food security. There were ten focus-group discussions held in three agroecology of which four were in *Woyina Dega* and three in each of the other two agro-ecological zones. The focus groups were composed of six to eight elders. One focus group in each of agroecology was composed of women who were perceived to have a deep knowledge of food security challenges and impacts of climate change on food security.

Quantitative data were collected through household survey, which comprised of the same sets of questions. The data set consisted of: food security variables (total grain produced; total grain purchased; total grain obtained through Food for Work (FFW); total relief food received; total grain products used for seed; and total marketed output. The survey also included questions on adaptation options (SWC, small-scale irrigation, agronomic practices, and livelihood diversification strategies); asset ownership (landholding, livestock ownership), social capital (local institutions/organizations households are membership); human capital and access to financial capital. The survey further covered data on households' demographic and socioeconomic characteristics (age, education, gender, and family size) as well as environmental variables such as access to early warning system, the-frequency of occurrence of drought, and their experience's in crop failure due to climate change and variability.

4.4.2. Methods of data analysis

Bothe descriptive and econometrics model were used to analyse the collected data. Percentage, chi-square test, and independent t-test were the descriptive statistics used in the analysis. Household food balance model and binary logit models were also used to classify households in to food secured and food in-secured categories, and to examine the determinants of household food security, respectively. The model selection procedure employed in this study involved two phases. The first phase was the selection of an appropriate model to categorize households into food secured and food in-secured, and the second phase was a selection of an appropriate model to determine factors that affect food security status in the study area. All quantitative data were analysed using STATA version 11.

Household Food Balance Model

To identify the food secure and insecure households, Household Food Balance Sheet was employed. In the calculation of kcal intake, the amounts of calorie available to a household was determined through an equation termed as Household Food Balance Model which was originally modified by Degefa (1996) from the FAO Regional Food Balance Model and later used for different studies (Mesay, 2010; Eshetu, 2000).

Household Food Balance Model is expressed as;

$$Nij = (\mathrm{Pij} + \mathrm{Bij} + \mathrm{Fij} + \mathrm{Rij}) - (\mathrm{Hij} + \mathrm{Sij} + \mathrm{Mij})$$

Where: Nij is net food available for household i in year j.

Pij is total grain produced by household i in year j.

Bij is total grain purchased by household i in year j.

Fij is total grain obtained through FFW by household i in year j.

Rij is total relief food received by household i in year j.

Hij is post-harvest losses to household i in year j. This takes 10.9% of the total harvest (Robin, 1998).

Sij is total crop utilized for seed from the home by the household i in year j.

Mij is total marketed output by household i in year j.

Finally, drawing on Degefa (1996), food security in the present study was measured in to the following steps: 1) net food grain available for each household in kilogram (Pi) was converted into equivalent total kilocalories using conversion factors used for Ethiopia (Agren, 1968); 2) the food supply at the household level calculated in step (1) was used to calculate calories available per person per day for each household; 3) following Federal Democratic Republic of Ethiopia Food Security Strategy, 2100-kilo calories per person per day was used as a measure of calories required (i.e. demand) to enable an adult to live a healthy and moderately active life. Then a comparison between the available (supply) and required (demand) grain food was made. Using 2100 kilocalories as cut off point, a household whose daily per capita caloric available (supply) is less than his/her demand was considered as food insecure, while a household who did not experience a calorie deficit during the year under study was regarded as food secured.

Binary Logit Model

It is commonly argued that Logit and Probit models are usually used to establish the relationship between household characteristics and a dichotomous response variable (food secured and food in-secured). The advantages of these models over the Linear Probability model are that the probabilities are bound between 0 and 1. Moreover, they best fit the nonlinear relationships between the response and the explanatory variables. The models specify a functional relationship between the probabilities of being food secured to various explanatory variables.

Gujarati (1995) also pointed out that in principle one can substitute the probit model for logistic model, as their formulations are quite comparable; the main difference is that the logistic model has slightly flatter tails than the cumulative normal distribution, i.e. the probit curve approaches the axes more quickly than the logistic curve. Therefore, the choice between the two is one of mathematical convenience. On this score, the logit model is generally used in preference to probit. In the same vein, Hosmer & Lemeshew (1989) stated that the logistic distribution has got an advantage over the others, in the analysis of dichotomous outcome variables, because it is extremely flexible and easily used model from the-mathematical point of view and results in a meaningful interpretations. Hence, the binary logit model was used for this study although both models may give a similar result.

Following Gujarati (1995), binary logit model is expressed as follows:

$$P_i = \mathrm{E}(Y = 1/X_i) = \frac{1}{1 + e^{-(\beta_o + \beta_1 X_i)}} \text{ --------------------- (1)}$$

For ease of exposition, equation (1) can be expressed as:

$$P_i = \frac{1}{1 + e^{-Z_i}} \text{ -- (2)}$$

Where: $Z_i = \beta_o + \beta_1 X_i$

If P_i is the probability of being food secured, then the probability of food in-secured is given by 1- P_i, which is expressed as follows:

$$1 - P_i = \frac{1}{1 + e^{Z_i}} \text{ -- (3)}$$

Therefore, this can be written as:

$$\frac{P_i}{1-P_i} = \frac{1+e^{Z_i}}{1+e^{-Z_i}} = e^{Z_i} \text{ -- (4)}$$

Where, Pi/ (1-P_i) is simply the odds ratio in favor of food secured; the ratio of the probability that the household will be food secured to the probability that it will be food in-secured. Taking the natural log of equation (4) above, it is possible to arrive at a log of odds ratio, which is linear not only in X's but also in the parameters,

$$L_i = Ln\left(\frac{P_i}{1-P_i}\right) = Z_i = \beta_o + \beta_i X_i \text{ ----------------------------- (5)}$$

Where:

P_i is the probability of being food secured ranging from 0 to 1

Z_i is a function of n-explanatory variables (X_i) and is expressed as:

$Z_i = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 +$ -------$+\beta_n X_n$

β_0 is the intercept or constant term,

$\beta_1, \beta_2, \beta_3, \beta_4,$ -------β_n are the slope of the equation in the model (parameters to be estimated),

L_i is log of odds ratio,

X_i is a vector of relevant household characteristic.

If the disturbance term (U_i) is introduced, the logit model becomes:

$Z_i = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 +$ ----$+\beta_n X_n + U_i$ -------------(6)

Finally, the parameters of the model are estimated using the Maximum Likelihood (ML) method (Gujirati, 1995; Maddala, 1981). Maddala (1981) noted that the ML method is a general method of estimation that is applicable to a large variety of problems. ML method suggests choosing or estimating the value of the parameter that maximizes the logarithm of the likelihood function itself and the same result is obtained. Hosmer & Lemeshew (1989) indicated that the method of ML yields value for the unknown parameters, which maximizes the probability of obtaining the observed set of data and such a method, is preferred when we have data at micro or individual level. However, there is a recognition that the OLS techniques can be used when the data set is sufficiently large and are grouped into the- interval.

4.4.3. Definition of variables and working hypotheses

After the analytical procedures are clearly delineated, it is necessary to identify the potential explanatory variables that can influence household food security. Consequently, review of the literature on economic theory, past research findings, experts and author's knowledge of the food security situation of the study area are used to identify the potential determinants of household food security in the study area. The dependent variable in this study is food security which is a dichotomous variable taking the value 1, if the household is food-secured and 0, otherwise. To dichotomize the household, the resulting average kcal consumed per adult equivalent per day is compared with the adequacy norm (the minimum subsistence kcal requirement) set by FDRE (2002) as 2100 kcal for the country. Based on acritical review of the literature, the following explanatory variables are hypothesized to have an influence on household food security.

***Distance from market center*:** this variable is a continuous variable measured in walking hours it took from the home of the household to the nearest market place. Closeness to market centers creates access to additional income via off-farm/non-farm employment opportunities, easy access to information on inputs and transportation (Gemechu *et al.* 2016; Dorward *et al*. 2003). It has been noted that the farther the market center is the lesser the income from the sale of farm produce. Especially for perishable commodities, if the market place is located far away from the farm, the commodity may perish before reaching the market and to avoid such incidences the farmer sells his output for cheaper price thus reducing the income and bringing negative impact on household food security. Therefore, it is hypothesized that there is a negative association between distance to the nearest market center and household food security.

***Age of the household head*:** it is a continuous variable measured in a number of years. Studies (Gemechu *et al.* 2016; Abebaw ,2003) indicated that age has a significant effect on household food security. That is, the older the household head, the more experience he/she has in farming and weather forecasting, and become more risk averter. As a result, the chance for such household to be food secured is high. Therefore, it is hypothesized that age of household head has a positive impact on household food security.

***Household family size*:** It refers to the total number of household members who lived and ate with household head for at least six months and is expressed in adult equivalent. In subsistence economy coupled with limited agricultural inputs, having large family size will demand more food than the labour they contribute to production (Gemechu *et al.* 2016; Zemedu and Mesfin 2014; Beyene and Muche 2010). Therefore, it is expected that household size and food security are negatively related.

Gender of the household head**:** it is a dummy variable which takes the value 1, if the household head is male, 0 otherwise. Female-headed households have less access to improved technologies, credit, land and extension services as compared to men (Greene, 2000). In contrast, male-headed households are in a better position to pull labour force than the female-headed ones. Christina *et al*. (2001) stated that women farmers may need a long adjustment period to diversify their income sources fully and to become food secured. Belayneh (2005) identified that male headed households are more food secured than female headed households. Therefore, it is hypothesized that female-headed households are less likely to be food secured as compared to male headed households.

The level of education of the household head*:* it is a continuous variable defined as the level of grades or schooling years attained by the household heads. A large body of literature noted that household heads with better educational background are believed to have a chance to diversify household's income sources, adopt better production technologies, accept technical advice from the extension workers and better manage their farm as compared to the illiterate ones (Tirfe & Hamda, 2011; Bogale & Shimelis, 2009; Abebaw, 2003). Educated households have a better chance of managing their farm by adopting improved practices, which in turn increased total yield. It is assumed that a literate household head often tends to adopt new skills and ideas which in turn have positive effects on food security (Tirfe & Hamda, 2011; Bogale & Shimelis, 2009; Abebaw, 2003). It is expected that educational status of the household head and household food security have a positive association.

The size of cultivated land*:* This variable represents the total cultivated land size which is owned, rented in, contracted in, and obtained through the gift of a household that have been measured in hectare. Households with larger farm size are more likely to be food secured as compared to those with smaller farm size (Tirfe & Hamda, 2011; Bogale & Shimelis, 2009; Belayneh, 2005; Ayalew, 2003; Mulugeta, 2002). A large size of cultivated land implies more production and availability of food grains and the possibility that the household gets more output is high as it remains the basic capital input in food production. It is hypothesized that farmers who have larger cultivated land are more likely to be food secured than those with a smaller area.

Livestock ownership*:* it is a continuous variable and measured in Tropical Livestock Unit (TLU). Households that own livestock can produce milk, milk products, and meat for direct consumption and for sale (Kifle & Yosef, 1999). Moreover, livestock contributes to the provision of draft power and manure which increase agricultural productivity. Farmers sell their livestock and livestock products and purchase food grains during seasonal food shortages. Increased livestock holding leads to decreased household vulnerability to food insecurity especially in times of drought when crops fail to yield the required amount of produces (Tirfe & Hamda, 2011; Bogale & Shimelis, 2009; Little *et al.* 2006; Belayneh, 2005). Thus, livestock owned is hypothesized to have a positive relation with household food security.

Access to credit service*:* it is a dummy variable taking the value 1, if the household accessed credit, 0 otherwise. Credit provides the opportunity to use inputs and this promotes production. Households that have an easy access to credit service have the possibility to invest in different farming and some other income-generating activities and improve their production. As a result, household's income and food consumption pattern will be improved (Beyene & Muche, 2010; Bogale & Shimelis, 2009; Kifle & Yosef, 1999). Therefore, it is rational to expect a positive association between access to credit service and household food security.

Access to extension services: it is a dummy variable takes the value 1, if a household got extension advisory services from development agents, 0 otherwise. Farm households that use advisory services by development agents are more likely to adopt new technologies and advance in their production. It is expected that extension service improves household's knowledge with regard to the use of improved variety and agricultural technologies and has positive impact on household food security (Anley *et al.* 2007; Tizale, 2007). Therefore, it is hypothesized that there exists a positive association between extension service and household food security.

Off-farm/non-farm income*:* it is a dummy variable which takes a value of 1, if the household participated in off-farm and/or non-farm activities, and 0, otherwise. Most farmers commonly generate their income from their farm. However, they occasionally look for the-external sources of off-farm incomes and non-farm activities to purchase clothes, inputs, food, and food related items (Markos, 1997). Many literatures noted that the ability to get access to off-farm/non-farm activities determine the success of households and their members in managing food insecurity which could serve as livelihood diversification strategies (Gemechu *et al.* 2016; Tirfe & Hamda, 2011; Barrett, 2010). On the other hand, off-farm activities can take labor away from agriculture and may decrease conservation investments and these might threaten household food security. Participation in off-farm/non-farm income sources is expected positively and/or negatively associated with food security.

Small-scale irrigation:-it is a dummy variable takes a value of 1, if the household used small-scale irrigation on their farm, 0 otherwise. A study by Hussain *et al*. (2004) confirms that access to reliable irrigation water can enable farmers to intensify cultivation, leading to increased productivity, overall higher production, and greater returns from farming. Tirfe & Hamda (2011); Bogale & Shimelis (2009); and Makombe *et al.* (2007) found that in moisture-stressed areas, getting moisture through irrigation would improve the situation and help to boost agricultural outputs. A study conducted by Woldeab (2003) in Tigray identified that small-scale irrigation has benefited households by providing an opportunity to increase agricultural production through double cropping and supplementing water during insufficient rainfall. Accordingly, it is hypothesized that participating in small-scale irrigation would have a positive influence on food security of the household.

Soil and water conservation measures: A soil and water conservation measures is a dummy variable takes a value 1, if a household practiced soil and water conservation activities, and 0, otherwise. In Ethiopia, erosion and soil degradation are constraints to food production since unsustainable management of soils, upon which agriculture depends, considerably affects food security (Beyene & Muche, 2010; Von Braun *et al*. 2005; Holden & Shiferaw, 2004). Practicing any soil and water conservation techniques will mitigate land degradation problem through maintaining soil fertility, which increases crop production, ceteris paribus. Thus, a household which practices any type of soil and water conservation measures is more likely to be food secured.

Occurrence of drought: it refers to a continuous variable with the number of times that drought occurred in the study area during the past 25 years**.** The experience shows that marked yield fluctuations and food insecurity are associated with climate variability. The country has been known by the reoccurring drought that resulted in food shortage. Food security in the country has been negatively affected by drought. Experiences revealed that drought has a significant influence on national annual per capita food supply (FAO, 2007a). It is, therefore, hypothesized that the number of times drought occurred in the area is negatively related to household food security.

Drought-tolerant seeds: it is a dummy variable that takes a value of 1, if farmers used improved and drought resistant seeds and 0, otherwise. Improved and drought tolerant seeds may withstand drought and erratic rainfall distribution when it is resistant to moisture stress. It augments agricultural productivity by boosting overall production, which in turn contributes to attaining food security at the household level (Lipton, 2005; Dorward *et al*. 2003). Hence, a household which uses improved seeds is expected to become more food secured than the non-users.

Access to early warning information: it is a dummy variable taking 1, if the household received early warning information and 0, otherwise. It is argued that farmers in drought-prone areas are responsive to changes in climatic conditions through what is commonly called "response farming". To reduce the production risk of total crop failure, they change their cropping patterns based on the climatic conditions they anticipate and observe (Alemu *et al.* 2008)**.** Similarly, findings from different areas reveal that better access to weather information helped farmers to use drought tolerant crop varieties, to invest in SWC measures, use irrigation, and diversify livelihood options in the response to climate change problem (Deresse *et al*. 2014; Nhemachena & Hassan, 2007; Maddison, 2006). Moreover, People-centered early warning information systems empower communities to prepare for and confront the impacts of climate extreme events (Hassan & Nhemachena, 2008). The effect of access to weather information on household food security is expected to be positive.

Social capital**:-**membership to social groups were used as a proxy for social capital. It is a continuous variable measured in a number of social groups in which the household is a membership. According to Tolosa (2009), local institutions functioning at the-community level and social capital play a role in maintaining food security at the individual and household levels. Dzanja *et al.* (2015) found that social capital has a positive impact on achieving food security. It is, therefore, hypothesized that social capital has a positive association to household food security.

4.5. Results and Discussions

4.5.1. Status of food security

Figure 4.1 presents the food security status of farm households that has been determined using descriptive analysis. The result of the Household Food Balance Model reveals that from the total sampled households, 57.8% of households were found to be food secured who fulfilled the minimum recommended daily calorie (2100 Kcal/AE per day as mentioned in FDRE, 2002). While 42.2% of them failed to supply this daily minimum requirement.

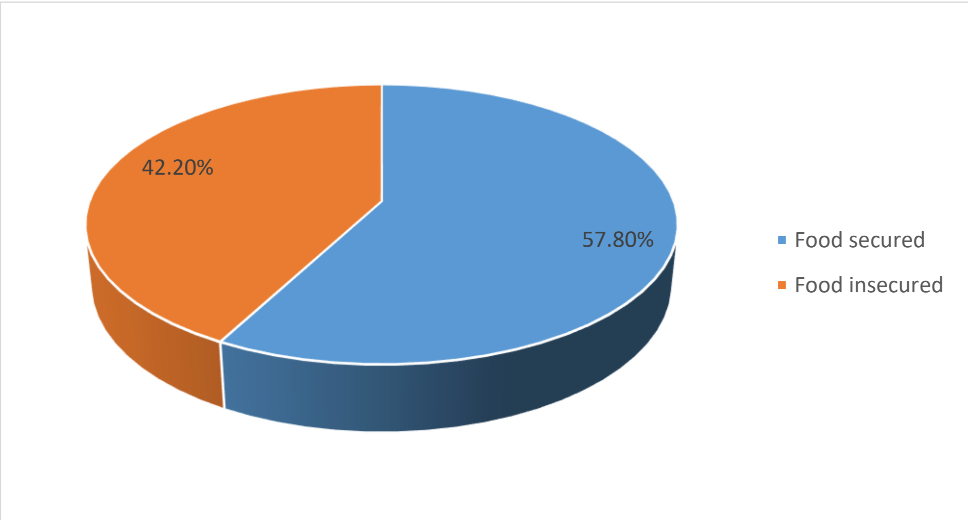


Figure 4.2: Percentage of food secured and food in-secured households

Table 4.1 and 4.2 present the descriptive statistics for dummy and continuous variables, respectively that are helpful to observe differences between food-secured and food in-secured households. The chi-square analysis shows that large proportion of food secured households used SWC, small-scale irrigation, drought tolerant seeds, and different livelihood options. The result further indicates that large proportion of food secured households are male headed households, accessed extension advisory services, accessed credit service, and early warning information as compared to their counterparts. The independent t-test result shows that there is a significant mean difference between food secured and food in-secured households with respect to social capital, landholding size, and distance to the main market, and livestock ownership.

Table 4.1: Association between discrete variables and household food security

Variable	Categories	Food secured (n)	Food in-secured (n)	Chi-Square value	Sig.
Agro-ecology	*Kolla*	54	86	35.722***	0.000
	Woyina Dega	137	55		
	Dega	57	40		
Soil and water conservation	No	154	149	20.630***	0.000
	Yes	94	32		
Small-scale irrigation	No	158	154	24.098***	0.000
	Yes	90	27		
Drought tolerant seeds	No	221	157	0.562	0.453
	Yes	27	24		
Off-farm/non-farm income	No	230	143	17.396***	0.000
	Yes	18	38		
Gender of the HH	Female	21	44	20.426***	0.000
	Male	227	137		
Extension service	No	67	102	37.720***	0.000
	Yes	181	79		
Access to credit	No	182	118	3.341*	0.068
	Yes	66	63		
Early warning information	No	89	111	27.209***	0.000
	Yes	159	70		

*, *** significant at 10%, and 1% respectively.

Table 4.2: Association between continuous variables and household food security

Variable	Food secured		Food in-secured		t-value	Sig.
	Mean	SD	mean	SD		
Age of the HH	45.75	12.257	45.70	12.878	0.039	0.969
Education status of HH	2.57	3.553	2.44	3.223	0.401	0.688
Family size	5.77	1.902	6.09	2.137	-1.650	0.100
Social capital	2.84	1.262	2.36	1.345	3.743***	0.000
Landholding size	3.04	1.605	1.76	1.415	8.758***	0.000
Distance to the market	1.55	0.795	1.79	.993	-2.645***	0.009
Livestock in TLU	7.98	4.805	4.61	4.472	7.455***	0.000
Occurrence of drought	4.33	3.06	4.21	3.353	0.382	0.703

*** Significant at 1%.

4.5.2. Econometric analysis

A binary logit model was used to identify potential explanatory variables affecting household's food security. Before running the analysis, variables assumed to have an influence on household food security were tested for multicollinearity and degree of association among variables using variance inflation factors and contingency coefficient, respectively. The test results show that there is no multicollinearity and association problem among the variables. Among 17 variables fitted into the model, 1) agroecology, 2) soil and water conservation, 3) small-scale irrigation, 4) drought tolerant seeds, 5) family size, 6) landholding size, 7) distance to the market, and 8) livestock ownership are found to be significant in determining food security of the household. The influence of all the significant variables is in the hypothesized direction. Table 4.3 below provides the parameter estimates of the binary logit model results.

Agroecology: The effect of agroecology can also be seen as significant where, on average, households in *Woyina Dega* agroecology are more food-secured as compared to those in *kolla* agroecology. On the other hand, households living in *Dega* agroecology do not shows significant differences on food security as compared to those in *kolla* agroecology. The odds ratio in favor of food security reveals that a shift from *kolla* agroecology to *Woyina Dega* agroecology increases the probability of the household being food secured by 2.5016. This may be explained by the fact that as one moves from *kolla* to *Woyina Dega* agroecology in the study area, the rainfall and vegetation cover increases which result in high crop production by the household and hence enhances food security. This implies that households in areas with *kolla* agroecology need to be paid special attention as compared to those in *Woyina Dega* agroecology.

Soil and water conservation: the model result in Table 4.3 shows that adoption of SWC measures found to have a significant influence on household food security at less than 1 percent significance level. This shows, in terms of food security, there exists a statistical difference between households practiced SWC measures and those who did not. On the basis of the results, one might conclude that investment on SWC measures generates substantial benefit in reduction of land degradation that has a substantial impact on agricultural productivity and that in turn has positive benefits on food security. The FGDs held in the study area reveal that using soil bunds, stone bunds, check dams and hillside terracing seem to yield better results in terms of contributing to household food security. The present study is consistent with studies conducted in other part of the country (Beyene & Muche, 2010; Holden & Shiferaw, 2004).

Small-scale irrigation: it had a positive and significant relationship with food security at 1% level, implying that households who have practiced small-scale irrigation on their farm are more likely to be food secured than those did not practiced. The odds ratio in favor of food security increases by the factor 5.335. Based on the results of this study, two possible explanations may be presented. First, irrigation provides an opportunity to grow a crop during non-rain season that provides multiple harvests per year possible. This is mainly because irrigation allows farmers flexibility in length or number of growing seasons (Burke & Lobell, 2010; Woldeab, 2003); second, it helps to avoid crop failure due to drought problem in areas where rainfall does not provide sufficient moisture like moisture-stressed areas of the rural areas of Muger sub-basin. This means households who used small-scale irrigation produce more food for household consumption and for sale and have better chance to be food secured than those who did not practiced irrigation on their farmland. A similar relation was observed by (Tirfe & Hamda, 2011; Bogale & Shimelis, 2009; Makombe *et al.* 2007)**.** It is, therefore, imperative to devise viable small-scale irrigation projects that critically consider the availability of suitable land, water resources, labor, non-irrigation production inputs, access to the market, and appropriate water-lifting technologies.

Drought tolerant seeds: Use of drought tolerant seeds is another variable which was found to have a positive and significant impact on household food security (at $p<0.05$). For example, farmers in the study area switched to DT-maize varieties from local maize varieties. The odds ratio for this variable in favor of food security is 3.519. This indicates that the probability of households to be food secured increases by 3.519 if a household has access and use of drought-tolerant seed. .This can be explained by the fact that in moisture stressed area due to climate change and variability like the study area, this input would reduce crop failure that in turn enhance crop production.

Family size: Family size is found to be negatively and significantly ($P<0.01$) impacted household food security in the study area (Table 4.3), implying that the probability of food security decreases with an increase in household size. The odds ratio in favor of the probability of being food secured decreases with an increase in the family size. More specifically, the odds ratio in favour of food security, *cetrisparibus*, decreases by a factor of 0.8345 as the family size increases by one member. The probable reason is that increasing household size within households whose agricultural land is less productive results to increased demand for food. This implies larger household sizes require more food expenditure and increased competition for limited resources. This creates a mismatch between the food demand and with the existing food supply from own production and this ultimately end up with the household becoming food in-secured. This result is consistent with a large number of empirical findings conducted in many different parts of Ethiopia and elsewhere in the world (Gemechu *et al*. 2016; Zemedu & Mesfin, 2014; Obayelu, 2012; Beyene & Muche, 2010; Bogale & Shimelis, 2009)**.**

***Size of landholding*:-**In agreement with *a priori* assumption, the size of landholding has a significant and positive influence on household food security. This means that households with large landholding produce more food for household consumption and for sale and have better chance to be food secured than those having relatively small size of land with the concept that the increase in agricultural output has been attained through the expansion of cultivated land (Van Der Veen, 2010; Haile *et al.* 2005). The result reveals that the odds ratio in favor of food security increases by the factor 1.3466 when the area under cultivation is increased by one hectare. This outcome is in line with the finding of previous studies (Aidoo, *et al.* 2013; Beyene & Muche, 2010; Bogale & Shimelis, 2009).

Distance to the market: distance to the major market is found significant and negatively related to food security in the study area. The odds ratio in favor of food security decreases by a factor of 0.6178 when the distance to the main market increased by one walking hour. The consensus that households nearer to market centers had better chances to be food secured than those who are away from market centers is due to the reason that households nearer to the market center have the probability of selling their produce and purchase food from the market. The results from the FGDs held in the study area show that households sold their livestock and livestock product to purchase food for family consumption during drought and crop failure problem. This result is in conformity with the results of previous studies (Gemechu *et al*. 2016; Feleke *et al*. 2005).

Livestock ownership: As it can be evidenced from many studies concerning household food security, livestock possession affects food security as it is the backbone of the farm economy especially in mixed farming systems. The result shows that total livestock owned by the household is found to be significant and positively related to food security in the study area. The odds ratio in favour of food security increases by a factor of 1.1061 when the amount of livestock owned by a household rises by one TLU. The possible explanations are: besides it creates employment opportunity for the member of the family, it provides milk and milk products, and meat for direct consumption and for the market; it contribute draft power and manure for crop production; and during famine and food shortage the farm households would be able to sell their own livestock and purchase food grains. This result is also in line with other empirical evidences in Ethiopia (Tirfe & Hamda, 2011; Bogale & Shimelis, 2009).

Table 4.3: Parameter estimates of determinants of household food security

Variables	Odds ratio	Z-value	p-value
Agro-ecology (Kolla)			
Woyina Dega	2.5016	2.26**	0.024
Dega	0.5385	-1.11	0.266
Soil and water conservation	12.0575	4.28***	0.000
Small-scale irrigation	5.3356	2.92***	0.003
Drought tolerant seed	3.5195	2.26**	0.024
Sex of HH	0.7132	-0.75	0.452
Age of HH	0.9991	-0.94	0.348
Education status of HH	0.9955	-0.11	0.912
Family size	0.8345	-2.54**	0.011
Social capital	1.1708	1.27	0.205
Size of landholding	1.3466	2.50**	0.013
Extension service	1.5349	1.43	0.153
Access to credit	1.0637	0.20	0.839
Distance to the market	.6178	-3.01***	0.003
Early warning information	1.4817	1.45	0.147
Livestock ownership in TLU	1.1061	2.71***	0.007
Occurrence of drought	1.0078	0.17	0.867
Cons.	0.4447	-0.99	0.324
Pseudo R2	0.3130		
Log Likelihood function	-200.67955		
LR Chi 2 (18)	182.85		
Prob > chi2	0.0000		
Number of observations	429		

, * Significant at 5% and 1%, respectively.

4.6. Conclusions and Policy Implications

The main objectives of the present study are to examine the food security status and the determinants of household food security in the face of climate change using sampled farm households. The household food balance model shows that 42.2% of the selected households are found to be food in-secured. The overall results reveal that adoption of adaptation options found to significantly and positively influence household food security. In addition, landholding size, and livestock ownership positively and significantly associated with household food security.

Our evidence suggests some important conclusions and policy attentions if the goals are both to enhance households' resilience to climate change shocks and to ensure household food security. Firstly, the results highlight the critical role of soil and water conservation measures, small-scale irrigation, and agronomic practices in household food security. Although not a panacea, soil and water conservation, small-scale irrigation and using different agronomic practices that are managed by farmers could contribute significantly to household food security. It is, therefore, imperative to devise viable projects on soil and water conservation, small-scale irrigation, and agronomic practices that consider the availability of suitable land, water resources, labor, production inputs, access to the market, and capital resources as well.

Secondly, our result with respect to livestock ownership suggests strong consideration of programs which improve the diversity and productivity of livestock assets such as improved feed, better animal health, market infrastructure, and improved variety that can adapt the emerging climate change and variability. Thirdly, the positive and significant relationship between land size and food security does not suggest economic reasons for land redistribution. This is because further land redistribution would result households to own smaller land than before and this could aggravate the risk of food insecurity in the area. The critical land shortage in the study area also tells the limited prospect of creating access to additional land through horizontal expansion. Hence, the result suggests promoting and supporting smallholders to make optimal land allocation decision and to use improved soil and nutrient management that will have potential impact on improving soil quality. It is also noted that family size and distance to the market are important factors negatively influencing household food security. To this end, promotion of labour-intensive technologies and the creation of labour-intensive and climate resilient rural employment opportunities would be the policy agenda to increase food security situation of the study area.

5. DOES ADAPTATION TO CLIMATE CHANGE AND VARIABILITY PROVIDES HOUSEHOLD FOOD SECURITY? EVIDENCE FROM MUGER SUB-BASIN OF THE UPPER BLUE-NILE

ABSTRACT

The purpose of this study is to evaluate the associated impact of adoption of adaptation to climate change and variability on household food security in the Muger sub-basin of the upper Blue-Nile of Ethiopia using a comprehensive data of 442 sampled households from four representative districts' in the sub-basin. The study used a propensity score matching approach to evaluate the impact of adaptation on household food security. Results showed that the decision to adopt adaptation options is found to be positively influenced by gender of household heads, family size, access to extension service, the size of landholding, and access to early warning information over the past many years. The results further revealed that farmers adopting any of the adaptation options had higher food calorie intake per day per adult equivalent than those who did not. A policy that promotes the adoption of soil and water conservation measures, small-scale irrigation, agronomic practices, and livelihood diversification strategies should be central to food security strategy in the study area.

Keywords: food security, impact, adaptation, climate change, Muger sub-basin.

Amare, A. and Simane, B. (2018). Does adaptation to climate change and variability provides household food security? Evidence from Muger sub-basin of the upper Blue-Nile, Ethiopia, *Journal of Ecological Process, 7(13): 1-12.*

5.1. Introduction

The impact of climate change on food security in Sub-Saharan Africa have largely been explored by a plethora of authors using either agronomic model or Ricardian analysis (Thornton & Herrero, 2014; Beddington *et al.* 2012; Thornton *et al*. 2012; Conway 2011; Deressa & Hassan, 2010). Empirical literature shows that Ethiopia is the most vulnerable country owing to its least adaptive capacity and low diversified economies (Stige *et al*. 2006). This becomes even more complicated where Ethiopia's agricultural systems have largely relied on rain-fed that has been closely associated with climate (World Bank, 2006b). It has been noted that extreme climate events such as drought and floods reduced one-third of Ethiopia's economic growth (World Bank, 2006).

A large body of literature has recognized adaptation as one of the policy options in response to climate change impact (IPCC, 2014; FAO, 2011; Smit *et al*. 1999; Smith & Lenhart, 1996; UNFCCC, 1992). It is seen as critical to a great extent to reduce the ultimate effect of climate change on agriculture so as to improve livelihoods and food security of rural households in the continent (Vermeulen *et al*. 2012; van de Giesen *et al.* 2010). "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" (FAO, 2011; IPCC, 2011).

Given serious problem posed by climate change, many potential adaptation options have been suggested for developing countries. For instance, soil and water conservation (SWC) practices have been suggested in response to soil erosion problem posed by climate (Amare & Simane, 2017a, 2017b; McCarthy *et al.* 2011; Amsalu & De Graaff, 2007). Based on data from a comprehensive survey of agricultural households across three agro-ecological zones in Muger sub-basin of the Blue-Nile basin, Amare & Simane (2017b) identified SWC measures are most widely used adaptation option in response to climate change. The use of this adaptation option was found to reduce soil erosion associated with short but heavy rains. Farmers adapting SWC measures to retain soil-water content and maintaining humidity during dry spells through an improved soil structure (McCarthy *et al.* 2011). Similarly, the use of different agronomic practices is considered as the potential adaptation option to the adverse effects of climate change on agriculture in the sub-basin. The analysis by Amare & Simane (2017b) in the Muger sub-basin showed that using agronomic practices such as drought-tolerant crop varieties, crop diversification, and improved crop varieties are another dominant strategies that are found to be used by smallholder farmers in adapting to the negative effects of climate variability and change as well as resultant changes in crop pest and disease pressures. Improved varieties (drought-tolerant varieties and/or short cycle) allow for increased productivity even during dry seasons (Lobell *et al.* 2008). Furthermore, Ellis & Freeman (2004) found that crop-diversification is used as a strategy for risk avoidance due to sharp fluctuations in crop yield or prices.

It is also disclosed that because of the unreliable and erratic pattern of rainfall and repeated drought, farmers in the study area practiced small-scale irrigation schemes on their farm. It is also observed that diverted streams, pond construction, and use of ground water using water pump are found to be the major means for small-scale irrigation in the study area (Amare & Simane, 2017b). In response to the adverse effects caused by climate variability and change, smallholder farmers have been diversifying their sources of livelihoods with an understanding of more diversified livelihood strategies lead them both to enhance incomes and spread the risk for smallholder farmers. This includes the use of on-farm, off-farm, and non-farm activities (Amare & Simane, 2017b; Morton , 2007). However, despite large investment in adaptation options in response to the adverse effect of recurrent drought and floods, households in the study area continue to suffer from food insecurity.

Studies have been undertaken to measure the impact of climate change on Ethiopia agriculture and explored possible adaptation options in response to its adverse effect (Deressa 2007; Kidane *et al*. 2006; NMA 2001). Insights from these studies are crucial in appreciating the extent of the problem and designing appropriate adaptation options. Notwithstanding the upsurge in the promotion of such adaptation options in recent years, there have been limited empirical studies that attempted to analyze their impacts on household food security (Ali & Erenstein, 2017; Asfaw *et al*. 2015; Gebrehiwot & Van Der Veen, 2015). For instance, Ali & Erenstein (2017) found that farmers adopting adaptation practices had higher food security levels than those who did not. Similarly, the analysis by Gebrehiwot and Van Der Veen (2015) using food security package program that has been implemented in Tigray regional state as an adaptation option to changing climate showed that the program has had a significant effect on improving household food calorie intake. Using a national survey conducted in Ethiopia, Asfaw *et al*. (2015) showed that the adoption of climate-smart agricultural practice have positive and significant impacts on the objective measure of food security (net crop income).

However, there is inadequate evidence to what extent that adoption adaptation impacted household food security in Ethiopia in general and in Muger sub-basin in particular. The results from previous studies are highly fragmented and are of little help in addressing local conditions in relation to adaptations to climate change. Moreover, the studies overlooked the likelihood household food security impact of adaptation at the household level. Using household-level data collected from 442 randomly selected samples in the study area, the aim of the current study is to provide a comprehensive analysis on the impact of adaptation to climate change and variability on household food security. The specific objective of the paper is, therefore, to estimate the effect of adoption of adaptation on household food security measured by household calorie intake/day per adult equivalent using propensity score matching technique. Addressing this question provides empirical evidence on the importance of adaptation in improving household food security. Furthermore, this study provides important insights and lessons on the importance of access to resources on the ability of the farm households to invest in climate change adaptation options that latter improve household's capacity to adopt adaptation options to changing climate. In addition, the finding of the study can be used in designing better adaptation interventions that can accommodate the existing resource potentials.

5.2. Methodology

5.2.1. Types of data and methods of data collection

The relevant data to this study were collected from both primary and secondary sources. Survey questionnaires, focus group discussions, and field observation were the data collection methods employed to collect primary data. The survey includes demographic, socio-economic, institutional, and environmental factors. Furthermore, data set consisted different types of adaptation options majorly used in the sub-basin, and major household food security variables. The details on methods used to collect the data, and the types of information collected are presented in chapter four of this thesis.

Treatment variable: the treatment variable is based on the question ‘’what adaptation options are households used to ameliorate the adverse impact of climate change and variability’’? The results from our analysis showed that SWC measures, small-scale irrigation, agronomic practices, and livelihood diversification are found to be the dominant adaptation options that farmers used in response to climate change and variability. These adaptation options were considered as a treatment variable in this analysis.

Outcome variable: the outcome variable used in this analysis is household food security status measured in household food calorie intake/day per adult equivalent. We used a household food balance model to compute the status of household food security using total grain produced by household; total grain purchased by household; total grain obtained through Food for Work by household; total relief food received by household; post-harvest losses to household; total crop utilized for seed from the home by the household; and total marketed output by household in a year of the survey period. The method is originally developed by FAO (1996) and later modified and used by many authors to measure food security status of households (Mesay, 2010; Eshetu, 2000; Degefa, 1996). Detail description of the food balance model, and results on the status of household food security are found in chapter four of this thesis.

5.2.2. Methods of data analysis

The data analysis was done using descriptive statistics such as mean, chi-square test and independent t-test. The chi-square test and t-test were used to examine mean differences between adopter and non-adopter of adaptation in terms of selected independent variables. The study also used a non-parametric method-Propensity Score Matching (PSM) - to evaluate the impact of adaptation on household food security.

Impact estimation strategies

If adaptation was randomly assigned to farmers, one could assess the impact of its adoption on households' food security by comparing the average consumption of adapters and non-adapters. In such a case, the average treatment effect (ATE) can be computed as follows:

ATE = $E\ (Y1 \mid D = 1) - E\ (Y0 \mid D = 1)$ ------------------------- (1)

This is based on the assumption that the output levels of the adopters before their adoption (E (Y0|D=1) can reasonably be approximated by the output level of non-adopters during data collection (E (Y0|D=0). Otherwise, estimation of ATE using the above equation is not possible since we do not observe E (Y0|D=1) though we do observe E (Y1|D=1) and (E (Y0|D=0). However, adaptation is rarely randomly assigned. Instead, adoption usually occurs through self-selection of farmers or, sometimes, through program placement. In the presence of self-selection or program placement, the above procedure may results in a biased estimation of the impacts of adaptation since the treated group (i.e. the adopters) are less likely to be statistically equivalent to the comparison group (i.e. the non-adopters) in a nonrandomized setting.

The literature shows various methods to address this selection bias. Some studies have adopted the Heckman two-stage method that assumes a normal distribution of unobserved variables. Another method employs instrumental variables (IV). This approach usually requires at least one variable in the treatment equation to serve as an instrument for the specification of the outcome equation. Moreover, both ordinary least square (OLS) and IV procedures restrict the model to take a linear functional form, implying that the coefficients on the control variables are similar for treatment and control groups (Ali & Abdulai, 2010).

In the absence of experimental data, the PSM is a widely used method to account for this sample selection bias, which is also employed in this study. The PSM technique pairs the treatment (adopters) and control (non-adopters) groups based on the similarity of observable characteristics (Ali & Abdulai, 2010). Unlike to the OLS and IV techniques, the PSM technique relaxes the assumptions of functional form, normal distribution of unobserved covariates and finding instrumental variables for the specification of the outcome equation. It only requires a set of observable covariates for matching and to determine causal effects of treatment on the outcome variable (Heckman & Vytlacil, 2007). One limitation of PSM is that it does not account for the unobservable variables directly; rather it assumes that selection is based on observable variables. PSM can be a better choice when instruments are weak or not available (Ali & Abdulai, 2010). PSM is defined as the conditional probability that a farmer adopts to climate change, given the pre-adaptation characteristics (Rosenbaum & Rubin, 1983).

With the above stated advantage, the current study used PSM technique to evaluate the impact of adaptation on household food security. The first step in estimating the treatment effect is to estimate the propensity score. To get this propensity scores, any standard probability model - logit, probit or multinomial logit- can be used (Rajeev *et al*. 2007). Since the propensity to adoption is unknown, the first task in matching is to estimate this propensity. Any resulting estimates of the program effect rest on the quality of the adoption estimate. This can be routinely carried out using a choice model. Which choice model is appropriate depends on the nature of the program being evaluated. If the program offers a single treatment, the propensity score can be estimated in a standard way using, for example, a probit or logit model, where the dependent variable is 'adaptation' and the independent variables are the factors thought to influence adaptation and outcome (Getachew *et al*. 2011b). Based on this, binary probit model was used to estimate the propensity score.

After obtaining the predicted probability values conditional on the observable covariates (the propensity scores) from the binary probit model estimation, matching was done using a matching algorithm that was selected based on the data at hand. Then the effect of household's adaptation in response to climate change on a given outcome (outcome in this study is food security measured in food calorie intake) (Y) is specified as:

$\tau_i = Y_i (D_i =1) - Y_i (D_i = 0)$ --------------------------------------(2)

Where;

τ_i is treatment effect (effect due to adaptation);

Y_i is the outcome on household i;

D_i is whether household i has got the treatment or not (i.e., whether a household adopted adaptation option or not).

However, one should note that $Y_i (D_i=1)$ and $Y_i (D_i = 0)$ cannot be observed for the same household at the same time. Depending on the position of the household in the treatment (adoption of adaptation), either $Y_i (D_i =1)$ or $Y_i (D_i = 0)$ is the unobserved outcome (called counterfactual outcome). Due to this fact, estimating individual treatment effect τ_I is not possible and one has to shift to estimate the average treatment effects of the population than the individual one. Most commonly used average treatment effect estimation is the 'average treatment effect on the treated (τ_{ATT}) and specified as:

$\tau_{ATT} = E (\tau / D=1) = E[Y (1)/ D=1] - E[Y (0)/ D=1]$-------------------(3)

As the counterfactual mean for those being treated, E[Y (0)/ D=1] is not observed, one has to choose a proper substitute for it in order to estimate the average treatment effect (ATT). One may think to use the mean outcome of the untreated individuals, E[Y (0)/ D=0] as a substitute to the counterfactual mean for those being treated, E[Y (0)/ D=1]. However, this is not a good idea, especially in non-experimental studies. Because it is most likely that components which determine the treatment decision also determine the outcome variable of interest.

In this particular case, variables that determine household's decision to adopt could also affect household's food security. Therefore, the outcomes of individuals from treatment and comparison group would differ even in the absence of treatment leading to a self-selection (Dehinenet *et al.* 2014; Getachew *et al.* 2011a). Subtracting E[Y (0)/ D=0] from equation 3 yields the following specification for ATT;

$E[Y(1)/ D=1] - E[Y(0)/ D=0] = \tau_{ATT} + E[Y(0)/ D=1] - E[Y(0)/ D=0]$ ------------ (4)

Both terms in the left hand side are observables and ATT can be identified, if and only if, $E[Y(0)/ D=1] - E[Y(0)/ D=0] = 0$. i.e., when there is no self-selection bias. This condition can be ensured only in social experiments where treatments are assigned to units randomly (i.e., when there is no self-selection bias). In non-experimental studies, one has to introduce some identifying assumptions to solve the selection problem.

The validity of the outputs of the PSM method depends on the satisfaction of two basic assumptions namely: the Conditional Independence Assumption (CIA) and the Common Support Condition (CSC) (Becker & Ichino, 2002). CIA (also known as Confoundedness Assumption) states given a set of observable covariates (X) which are not affected by treatment (in our case, adoption of adaptation), potential outcomes (household food security measured by food calorie intake) are independent of treatment assignment (independent of how adoption decision is made by the household). This assumption implies that the selection is solely based on observable characteristics, and variables that influence treatment assignment (adoption decision is made by the household) and potential outcomes (household food security) are simultaneously observed (Getachew *et al*. 2011b). The common support condition entails the existence of sufficient overlap in the characteristics of the treated and untreated units to find adequate matches (or a *common support*).

Three commonly used matching algorithms, namely Nearest Neighbor Matching (NNM), Kernel-based Matching (KM), and stratification matching (SM) were employed to assess the impact of adaptation on households' food security. The NNM method matches each farmer from the adopter group with the farmer from the non-adopter group having the closest propensity score. The matching can be done with or without replacement of observations. NNM faces the risk of bad matches if the closest neighbor is far away. The KM method uses a weighted average of all farmers in the adopter group to construct a counterfactual. The major advantage of the KM method is that it produces ATT estimates with lower variance since it utilizes greater information; its limitation is that some of the observations used may be poor matches.

5.3. Results and Discussions

5.3.1. Adaptation options

The study explored four dominant adaptation options used by smallholder farmers in response to the adverse effects of climate change and variability in the study area. These include, soil and water conservation (28.7%); small-scale irrigation (27.4%); livelihood diversification (13.6%); and agronomic practices (11.5%). The rest 18.8% of households are found to be non-adopter of the adaptation options. To evaluate the total impact of these adaptation options on household food security using calorie intake, we created a new data set by driving a binary variable equal to 1, if households adopted either of the adaptation option; and 0, if households did not adopt any of the adaptation options. Based on this categorization, we found that 81.2% of the households are falling under adopter group, and the remaining 18.8% of the households are non-adopter.

5.3.2. Descriptive analysis

Table 5.1 and 5.2 present the t-test and chi-square comparison of means of selected variables between adopter's and non-adopters of adaptation, respectively. Results show that positive and significant difference is observed in terms of age of household head, family size, social capital, landholding size, and distance to the nearest market, livestock holding, and number of drought events between adopters and non-adopters of adaptation. Moreover, adoption of adaptation is also distinct in terms of agroecology, gender of the household head, access to extension service, and access to credit.

The results also reveal that adoption of adaptation is significantly distinguishable in terms of food security status, measured in terms of household food calorie intake/day per adult equivalent. As far as calorie intake is concerned, adopters of adaptation tend to have higher calorie intake as compared to the non-adopters. The mean calorie intake/day per adult equivalent is 2850 kcal, and 1549 kcal for adopters and non-adopters, respectively (Table 5.1).

Table 5.1: Descriptive statistics of continuous variables used in regression

Variable	Adopters (N= 359)		Non-Adopters (N=83)		t-value	Sig.
	Mean	SD	Mean	SD		
Age of HH	46.09	12.392	42.72	13.544	2.076	0.040
Education of HH	2.58	3.470	2.33	3.212	0.639	0.524
Family Size	6.09	1.993	5.08	1.945	4.209	0.000
Social Groups	2.72	1.319	2.24	1.274	3.057	0.003
Land ownership	2.73	1.678	1.47	1.183	8.016	0.000
Distance to market	1.59	0.858	1.88	.998	-2.457	0.016
Livestock ownership	6.85	4.893	4.92	4.870	3.249	0.001
Climate	4.44	3.328	3.43	2.073	3.501	0.001
Food security Status	2850	2441.88	1549	648.59	13.487	0.000

Table 5.2: Descriptive statistics of categorical variables used in regression

Variable		Adopters (359)	Non-Adopters (83)	Chi-Square	Sig.
Agro-ecology	*Kolla*	107	36	8.734	0.013
	Woyina Dega	163	37		
	Dega	89	10		
Gender of the HH	male	341	34	152.980	0.000
	female	18	49		
Access to extension service	yes	254	12	89.152	0.000
	no	105	71		
Access to Credit	yes	115	16	5.260	0.022
	no	244	67		

5.3.3. Determinants of adoption of adaptation

Given that variety of differences exist between adopters and non-adopters of adaptation, it is important to control for these potential underlying effects in order to ensure reliable impact estimates. In order to provide information on household's probability of adopting adaptation on household food security, a probit model is used to match adopter and non-adopter households. The results of the probit model presented in Table 5.3 depicts estimated parameters on the adoption of climate change adaptation.

The results from the probit model estimates indicate that gender is positively and significantly related to the adoption of adaptation at less than 1% significance level. The result is in conformity with the previous argument by showing that male-headed households had better opportunity to take an adaptation measure than female household mainly due to cultural and social barriers that limit women's access to land and information for climate change (Deressa *et al*. 2014; Asfaw and Admassie, 2004). The model result of this study reveals that size of cultivated land significantly increases the likelihood of using adaptation at 5% significance level. On average, the probability of using adaptation increases by 10.7% as the proportion of farm size increases by a hectare. Furthermore, access to extension services has a significant influence on adoption of adaptation. As expected, the influence of access to extension service on farmer’s decision to invest in adaptation is significantly positive ($p < 0.000$). Having access to extension service increases the probability of adoption of adaptation by 22.8%.

Better access to early warning information about drought and flood before it happened has a significant and positive impact on the likelihood of using adaptation at 10% significance level. The result reveals that getting access to climate warning about drought and/or flood increases the likelihood of using adaptation by 5.04%. This finding is in line with the results of previous studies that showed a positive relationship between early warning information and farmer’s decision to adopt adaptation option (Phillipo *et al*. 20015; Deressa *et al*. 2014). On the contrary, livestock holding in TLU negatively influences household's decision to adopt adaptation at 5% probability level. This result reveals that a unit increase in a number of livestock in TLU would result in a 3.35% decrease in the probability of adopting adaptation. Finally, the results from the probit model show that farmers decision to adopt adaptation does not significantly influenced by agroecology, access to credit, distance to the nearest market, social capital, education status, and age of the household head.

Table 5.3: Estimation of propensity score through probit regression model

Adoption	Coef.	Std. Err	z-value	Sig.
Agroecology	0.31019	0.20626	1.50	0.133
Gender of HH	1.9498	0.24496	7.96***	0.000
Age of the HH	-0.00252	0.00876	-0.29	0.774
Education	-0.03589	0.03203	-1.12	0.263
Family size	0.16198	0.05581	2.90***	0.004
Social capital	0.14003	0.10045	1.39	0.163
Farm size	0.32195	0.10689	3.01***	0.003
Access to extension service	1.3541	0.22822	5.93***	0.000
Access to credit	0.31800	0.24587	1.29	0.196
Market distance	-0.15333	0.11874	-1.29	0.197
livestock	-0.07169	0.03354	-2.14**	0.033
Early warning information	0.09858	0.05041	1.96*	0.051
_cons	-3.2501	0.69312	-4.69***	0.000

Probit regression
Number of observation =442
LR chi2 (12) =231.61
Prob>chi2 =0.000
Pseudo $R^{2} = 0.5425$
Log likelihood =-97.676355

***,**,and * significant at 1%, 5%, and 10%, respectively.

5.3.4. Estimation results of propensity scores

After calculating the propensity scores, the NNM method, KM, and SM were employed to match the control group of individuals (non-adopter) to the treated group (adopter) based on similar propensity scores. During the matching process, all the matching methods employed discards the unmatched non-adopters and hence, they lead to the reduction in sample size for the post-matching impact analysis. The region of common support is [0.01697335, 0.99999403] and the balancing property also satisfied.

The results confirm there exist a considerable overlap in common support. Figure 5.1 shows the distribution of propensity scores of matched and unmatched individuals in both groups. The result guarantees a sufficient overlap in the distribution of the propensity score between adopter and non-adopter. The bottom half of the graph stands for the propensity score distribution for the non-adopters and the upper half refers to the adopters. The densities of the scores are on the y-axis. In the next step, we calculated the average adaptation effects on the status of household food security.

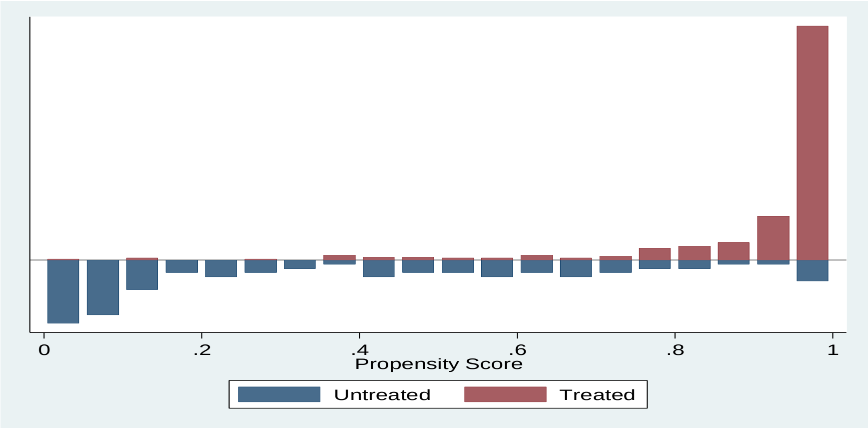


Figure 5.1: Propensity score

5.3.5. Estimation of the treatment effect

The correlation between adoption of adaptation and household food security outcome such as household calorie consumption/day/ adult equivalent is theoretically complex and there are further empirical pitfalls regarding the impact evaluation problem. Despite this pitfalls, we estimated the calorie consumption effect of climate change adaptation based on cross-sectional data available.

Table 5.4 presents the estimated effects of the adaptation on the household food security by NNM, KM, and SM methods. The post-matching result from NNM reveals that adaptation tends to positively and significantly affect household calorie intake. The estimates of NNM shows that adoption of adaptation improves household food calorie intake by 635 kcal /day per adult equivalent. Similarly, the KM result reveals adopting either of the adaptation options also guarantee favorable effect on household food security. This means that as compared to similar / matched households that didn't adopt any of the adaptation options, households that did adopt experienced a 660 kcal/day per adult equivalent higher number of calorie intake. Similarly, the SM result shows that household's adopting adaptation has 825kcl higher than their counter part.

This implies that adoption of adaptation has a causal influence on household food security status. This indicates that the return to investment in SWC measures; small-scale irrigation; agronomic practices; and diversifying livelihood strategies do generates reliable results, especially in areas where climate change and variability adversely affects agriculture which is considered as the main livelihood option of the households. This reaffirms the narrative from the results of the FGDs in which not adopting SWC measures such as stone bund, soil bund, check dam, and terraces, coupled with the lack of small-scale irrigation practices, undermines the prospect of household food security. This is consistent with the secondary literature that shows a positive effect of technology adoption on food security (Magrini & Vigani, 2014; Amare *et al*. 2012).

Table 5.4: Impact of adaptation on household food security

Outcome indicators	Matching algorisms	Matched samples		Impact (ATT)	t-test
		Affected	Non-affected		
Food security	NNM	359	27	634.93	8.447
	KM	359	80	660.163	9.941
	SM	359	80	825.114	9.218

5.4. Conclusions and Policy Implications

We have analyzed the effects of adoption of adaptation on food security among smallholder farmers in Muger sub-basin of the upper Blue-Nile basin of Ethiopia. The study used the non-parametric method involves the application of a binary propensity score matching estimator. Use of SWC measures, small-scale irrigation, agronomic practices, and livelihood diversification strategies are the dominant climate change adaptation options used by the farmers in response to risks related to climate change and its associated variability in the study area. Adaptation decisions are significantly affected by various socio-economic, institutional, environmental and demographic factors. In particular, gender, family size, land ownership, access to extension service, and livestock ownership are important factors influencing farmer's decision to adopt adaptation.

The impact evaluation results show that adoption of climate change adaptation has generated a significant positive impact on household food security. Farm households that did adopt would benefit the most from adoption. These results generate a strong evidence for the positive impact of adoption of climate change adaptation that limit the adverse effect of climate change on households' livelihoods to alleviating food insecurity in the study area. However, farmers are yet unable to enjoy the full benefit of adaptation due to various constraints. These results open a scope for policy to further promote the adoption of climate-change adaptation options that seem to be particularly important for households who have the least capacity to adapt.

Firstly, the results highlight the importance of awareness and knowledge about adaptation options and its risk-reducing potential. Hence, policy should target increasing the awareness of climate change adaptation options and its benefits using agricultural extension services. Secondly, the result points to the importance of access to resources on the ability of the farm households to invest in climate change adaptation options. The policy option should give attention to resource-constrained farmers. Thirdly, the result indicates the importance of gender of the household heads to adopt adaptation. Hence, policy should target gender-based adaptation to climate change and variability. All these policy implications may lead to better adoption of adaptation and may be able to support farmers to ensure food security.

On the basis of the results, one might deduce that investment in climate change adaptation options does generate substantial benefit in terms of achieving household food security because adaptation increase food availability through boosting crop productivity; and maintain food stability by reducing the risk of crop failure, making the household less vulnerable to negative shocks, and improving their resilience capacity. However, such an aggregation does not provide adequate evidence to make firm conclusions. This paper posed a concern to see the potential effect of each adaptation options on household food security and to identify the most successful one to lift livelihoods for further research. Lastly, in addition to the policy relevance of these findings to the study area, it could be replicated or applied in the area where similar problems might prevail, particularly in other parts of the country.

6. SYNTHESIS

The research presented in the five papers that form the core of this thesis has aimed to contribute to answering the questions why and how farmers' vulnerability differs across different agro-ecological zones to the changing climate; how they would and could respond to climate change and, in particular, how these responses impacted household level food security. This synthesis chapter first provides an overview of lessons learned of research on the three central research findings- vulnerability, adaptation, and food security- that are inherently interconnected in the context of climate change and variability. Next, the implications of this research work are introduced that build on the work presented in the five papers followed by suggestions for future research. Finally, this section provides the contribution of the research in terms of empirical, methodological and theoretical.

6.1. Vulnerability to Climate Change and Variability

The central tent of this study is that smallholder farmers' vulnerability has been increasingly primarily due to high exposure, high sensitivity, and low adaptive capacity to climate change and variability. These three contributing factors varies across the three agro-ecological zones. The livelihood vulnerability index results provided detail information regarding differences in vulnerability of farmers' across the three agro-ecological zones. Farmers in *Kolla* agro-ecology deemed to be most vulnerable with the highest exposure, and sensitivity and lowest adaptive capacity to climate change and its associated variability. Differences in use of small-scale irrigation, level of crop diversification and status of food insecurity largely explained the variation in sensitivity of smallholder farmers' to climate change and variability across agro-ecological settings. Adaptive capacity of farmers in the sub-basin has been influenced by a combined effects of various socio-economic, institutional, and environmental factors. It is further noted that lack of diverse livelihood options and lack of well-developed infrastructure have weaken farmer's adaptive capacity. Socio-economic factors (e.g. asset ownership) and social capital are another critical elements that explained variations in adaptive capacity of farmers in different agro-ecological settings in the sub-basin (Paper one). Given the current vulnerability status in the sub-basin, and if things go business as usual, a moderate climate change would have a larger potential to disrupt the livelihoods of smallholder farmers and that could lead to higher sensitivity, higher exposure and lower adaptive capacity.

An important lesson learned from the research presented here is that climate change disproportionately affects farmers living in different agro-ecological settings in the sub-basin both due to the existing variation in biophysical and socio-economic factors (Paper one). This result is theoretically grounded using integrated vulnerability assessment. The result concurs with this theory in that vulnerability is determined by the combined effects of biophysical and socio-economic factors. Despite differences in internal biophysical factors, differences in institutional, and economic factors explain farmers' vulnerability to climate change and variability. Agro-ecological based vulnerability analysis gives a good entry point to analyse which type of adaptation options should be targeted to which agro-ecological zone.

6.2. Adaptation Options and Its Determinants

Climate change is set to be particularly disruptive in poor agricultural communities. We argue that exploring adaptation options and investigating the impact of socio-economic, institutional, environmental and other conditioning factors that determine farmer's decision to adopt adaptation options in the study sub-basin provides useful insights on farmers' decision and also help in designing effective incentive structures to overcome barriers to adoption.

The work on the determinants of farmers' decision to adopt adaptation options on Muger sub-basin (Paper two) is a good case study of how farmers responded to off-set the negative impact and what factors determine their decision to adopt. This paper appreciated the complex nature of adaptation decision that shaped mainly by institutional, economic, social and environmental dimensions. The work gives focus on identification of various types of adaptation options that farmers conveyed to reduce the potential impacts of climate change. The results showed that farmers adopted varied adaptation options to adjust to changes in their environment. It is also observed households constrained to adopt adaptation options to the specified change. Farmers in the sub-basin used a range of adaptation options: which includes i) soil and water conservation; ii) small-scale irrigation; iii) agronomic practices; and iv) livelihood diversification strategies.

The analysis of determinants of adaptation options revealed that several factors influenced farmer's decision to adopt adaptation options. The use of soil and water conservation was found to be influenced by gender of the household head; distance to the nearest market; early warning information; and size of farmland. The results further revealed that adoption of small-scale irrigation was positively influenced by education; social capital; and access to credit. The study also highlighted that early warning information; crop failure experience; and size of farmland positively influenced the decision to use agronomic practice, while sex of the household head and distance to the nearest market negatively influenced the decision to use agronomic practices. The result further showed the positive influence of education on adoption of livelihood diversification. Adoption of livelihood diversification was also negatively influenced by gender of the household head (Paper three). Overall, resource availability enables farmers to implement adaptation decisions, the lack of which presents the household with a significant challenge of adopting the adaptation options. It is also noted awareness of climate change and measures to mitigate its effects is thus depicted as a key hurdle in the adaptation process.

This study leads to the conclusion that adaptation to climate change must be seen as part of a broader socio-economic, institutional and environmental factors (Paper three). It is also argued that future development interventions should also aim at increasing the extent to which institutions are in place and technologies, expertise, and other resources are available to assist farmers' decision to adopt adaptation options that could later improve household food security. This result argues with sustainable livelihood framework. A range of livelihood capitals are the major means of farmers to pursue adaptation options in response to the adverse impact of climate change. It is also noted that institutions and organizations influence farmers' decision to adopt adaptation options so as to improve their livelihood outcome, food security.

6.3.Adaptation: Increased Household Food Security

In the fourth article of this thesis, an analysis of the status of household food security, and major socio-economic, environmental and institutional factors associated with household food security was undertaken. This enables us to better understand the main factors influencing household food security and recommend policy actions best adapted to tackle the problem. The study confirms about 42% of the sampled households failed to meet the minimum daily calorie intake per adult per day (Paper four). The result further showed that productive farm assets – principally farm size and livestock owned are a critical factors determining household food security. In the study area, livestock is a source of cash and serves as a buffer against climatic uncertainties and towards the end of every crop year when most households faced food shortage problems. The empirical analysis further provides evidence that soil and water conservation, small-scale irrigation and agronomic practices are significantly influenced household food security.

Along with the work on adaptation came also the increasing recognition of the need to better understand the extent to which these adaptation options can serve to enhance household food security. The research presented in this paper has helped to move the concern of our understanding from identifying adaptation options to analysing the impact of these adaptation options to actually improve household food security. The finding showed that climate change adaptation positively affect household food security that has been measured in calorie intake per adult equivalent per day. Efforts made to combat the effect of climate change and variability in the sub-basin has produced a remarkable results. Farmers adopting adaptation had higher food security level than those who did not. More specifically, the adaptation has raised food calorie intake ranging from 634 to 825 using different matching techniques (Paper four). This entails if we allow someone to use adaptation options, his/her food calorie intake would substantially increase as compared to the one who do not used the adaptation. This impact evaluation study benefits from sustainable livelihood framework. Climate change adaptation at farm level can thereby have significant livelihood outcomes in addition to reducing exposure to climate risks. The advances in the adoption of adaptation has contributed significantly to household food security. This is crucial to support decision about designing and implementing impactful adaptation against hazards related to climate change.

Despite the distinct foci of each of the article presented, there are clearly considerable areas of overlap. Understanding the implication of adaptation for food security would benefit from drawing on aspects of all results: as vulnerability assessment provides particular insights in to patterns of vulnerability and facilitates the understanding of factors that contribute to vulnerability which is an entry point and important for adaptation planning; and analysis of adoption of adaptation options provides farmers decision pattern; and highlights the role of adaptation to enhance food security are crucial to support decision to identifying potential adaptation options that fit to a particular context. Theoretical frameworks adapted from integrated vulnerability assessment, food security, and sustainable livelihood approach contribute to this study in liking vulnerability, adaptation and food security in practice.

6.4. Policy Implications and Future Research

6.4.1. Policy implications

Soil and water conservation measures, small-scale irrigation practices, agronomic practices, and livelihood diversification strategies used by the local farmers' in response to risks emanated from climate change and variability are faced with several problems. Though farmers apply a rage of these adaptation options, their activities are largely constrained by problems that exist at the different level of decision-making. Therefore, creating enabling environment to the adoption of adaptation options would lead to reduced vulnerability and increased food security. A necessary precondition that the policy attention should focus for the success of adoption of these adaptation options are: 1) setting agro-ecology specific priorities for intervention; 2) Based on the evidence that climatic condition plays an important role in farmers' adoption decisions, it is logical to conclude that improving access to reliable climate forecast information is a key to facilities adaptation. However, the forecast that focus on over a large spatial scale and described in a more qualitative terms could not support farmers decision making. Thus, timely provision of climate specific information that contains information about timing (e.g. onset of rainy season or dry spells) interpreted at the local scale aimed at enhancing preparedness of farm households to extreme events, and increasing farmer awareness is an important policy attention. To this end, linking farmers to new sources of information on climate variability will be important, but translating the risks and potential margin of error that exist in a way that farmers can understand and use in decision making is equally important; 3) give attention to expand availability of infrastructural facilities such as market, access to credit, health services, and veterinary services thereby enhance adaptive capacity; 4) increasing the affordability of climate adaptation options by augmenting the farm household assets and lowering the cost of adaptation through creating effective microfinance institutions. This is crucial to empower farmers to access, test, and modify these adaptation options; and 5) encourage social capital formation among rural communities. This can include encouraging formal and informal farmer and community groups through training and formalization. It can be important vehicles for information dissemination and mutual support to help farmers acquire information and resources needed for implementing practices that enhance adaptation.

Another important issue often get less policy attention is developing improved and drought tolerant crop varieties that would have the potential to off-set the impact of climate change and variability. Thus, future policy to develop and promote drought-tolerant crop varieties can support farmers to better cope with climate change. Over all, based on the evidence that adaptation plays an important role in achieving food security, it is imperative that future policy has to aim at promoting/devising viable projects on soil and water conservation measures, small-scale irrigation and agronomic practices that consider the availability of suitable land, water resources, labor, production inputs, access to the market, and capital resources.

Supporting these adaptation options in the sub-basin provide more positive form of household food security.

6.4.2. Future research

A wide range of issues ranging from vulnerability, adaptation, food security, to impact of adaptation on household food security were raised and discussed in the different chapters of this research work. A lot remains, however, to be done in this area. Based on the findings of this thesis, further investigations are suggested in the following areas:

1).The present study is at the sub-basin/agro-ecology level and it can only provide an indicative vulnerability at more or less larger scale. Our observation showed that there still a significant variation in spatial heterogeneity, socio-economic, infrastructure development, and environmental diversity within agroecology. Due to these considerable diversities, both the impacts of climate change and the response measures are likely to be highly spatially variable. Hence, more detailed agro-ecosystem specific vulnerability information can be generated through further research in the study area. Thus, it is suggested that agro-ecosystem specific analysis that would be adequate to capture diversity in topography, socio-economic, and environmental issues should be considered for a more holistic understanding about where to implement and what types of adaptation options.

2). The results reported in this thesis provide useful insights on socio-economic, institutional, and environmental factors affecting climate change adaptation and vulnerability, however, it provides little insight in to bio-physical factors determining vulnerability, adaptation and food security. To better address reduced vulnerability and increased food security concern that are central to economic and sustainable development agenda, a future research that integrates the bio-physical and socio-economic, institutional and environmental aspects of agricultural system could be helpful to provide coherent and systematic frameworks that might facilitate more systematic search for appropriate adaptation options.

3).This research attempted to evaluate the aggregate impact of SWC measures, small-scale irrigation, agronomic practices, and livelihood diversification strategies on household food security in its entirety. The research modelled impact analysis in a dichotomous adaptation choice framework to capture useful economic information contained in adoption decisions. This is important to design a comprehensive extension package of these adaptation options that would deliver the highest payoff. However, the study is far from providing sufficient information for a specific impact of each adaptation option on household food security. This would help to design a specific adaptation package for specific contexts. Given this understanding, we suggest further research to evaluate disaggregated impacts of each adaptation option on household food security in the sub-basin. This probably would help to prioritize adaptation options based on the potential benefits that each adaptation option would generate and the capacity to implement.

4).This research used households as a unit of analysis to examine adaptation and food security. However, this research is far from evaluating the impact of adaptation to different groups of smallholder farmers that would have different level of vulnerability to climate change. The determinants, and impacts of adaptation to different household typology- poor, medium, and rich household- will vary. To address this issue, we recommend further research to critically examine vulnerability, adaptation, and impact of adaptation on food security for different social groups.

6.5. Contribution of the Research

This sub-section is devoted to discuss the knowledge and methodological contribution of the research. It contribute to the knowledge domain and methodological orientation on smallholders vulnerability to climate change, the mechanism's they designed to adapt to the existing change, and the impact of these mechanisms on household food security in three ways: empirical, methodological, and theoretical.

1. Empirically, the research contribute in documenting the contextual knowledge regarding the complex realities of farmer's vulnerability to climate change and variability, adaptation options and household food security in the study area. It explains what makes smallholder farmers vulnerable to climate change and its associated variability, and what makes them food insecure. In doing so, the research helps to fill the gap in understanding the level of farmer's vulnerability and patterns of adaptation options that latter help to improve household food security. The analysis in the empirical chapters reveal considerable variations among households in their level of vulnerability, in their choice of adaptation options in response to adverse impact of the changing climate, and the interaction between adaptation and food security. I would argue that the insights and observations from this research helps to form bodies of knowledge on rural livelihood vulnerability and food security.

2. Methodologically, the research contributes in various form to further analyse vulnerability and food security:

   i) ***Extending livelihood vulnerability index***. Although livelihood vulnerability index is an important tool to measure farmers vulnerability to climate change and variability, it is requires to customise the indicators to the local context. In analysing this issue, I have tried to reconstruct new indicators on the basis farmer's experience, ground realities, and from literature. I hope future research will find the approach useful.

   ii) ***Linking the context of vulnerability, adaptation and food security***. Unlike many studies that choose vulnerability or adaptation or food security independently in their analysis, the current study has attempted to look at the link among farmer's vulnerability, their responses to the existing change, and the potential impact of these responses on their food security. I would argue that no previous research on these theme tried to integrate the concepts as the current study does.

   iii) ***Including environmental factors in food security analysis***: previous studies in food security analysis mainly focussed the socio-economic and bio-physical factors as the underlying factors for household food security. Environmental factors such as early warning information and occurrence of drought/flood were not indicated in their analysis.

3. Theoretically, this research attempted to review the interface between sets of main theories and concepts that make the foundation of the research. This helps to frame the research and to clearly see the divergence and convergence between theories and observations.

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APPENDICES

Appendix I: Conversion factors used to estimate TLU

Animal Category	Tropical Livestock Unit (TLU)
Calf	0.25
Donkey (young)	0.35
Weaned calf	0.34
Camel	1.25
Heifer	0.75
Goat/sheep (adult)	0.13
Cow and ox	1.0
Goats/sheep (young)	0.06
Horse	1.10
Donkey (adult)	0.70
Chicken	0.013

Source: Strok *et al*. (1991)

Appendix II: Conversion factors used to compute Adult-Equivalent

	Sex	
Age group (years)	Male	Female
<10	0.60	0.60
10-13	0.90	0.80
14-16	1.00	0.75
17-50	1.00	0.75
>50	1.00	0.75

Source: Strock *et al*. (1991)

Appendix III: Energy content of various everyday food items (KJ= 240 calories)

Food items	KJ/g
Barley	14
Wheat	14.2
Wheat bread	10
Maize	14.6
Sorghum	14.5
Millet	13.9
Rice	14.6
Teff	14.2
Beans and peas	13.9
Soy beans	14.7
Cow pea	11.8
Ground nut	24
Sunflower seed	23.9
Lentil	14
Sweet Potato	5.1

Appendix IV: Survey Questionnire

Addis Ababa University
College of Development Studies
Survey on Linking Vulnerability, Adaptation and Food Security in a Changing Climate: Evidence from Muger Sub-Basin of the Upper Blue-Nile Basin of Ethiopia
.

Introduction

Dear Respondent;

My name is Abayineh Amare. I am a PhD Student at Addis Ababa University College of Development Studies. Currently I am doing research on Linking Vulnerability, Adaptation and Food Security in a Changing Climate: Evidence from Muger Sub-Basin of the Upper Blue-Nile Basin of Ethiopia. The objective of this questionnaire is to collect primary data on socio-economics, ecological, vulnerability, adaptation and food security, and development related information that are required to assess the vulnerability of smallholder farmers induced by climate change and food security. Therefore, you are kindly requested to give your response freely and accurately to the success of this study. You should be confident that the data/information which you give us works only for this study.

Lastly, I thank you for your cooperation

Name of Enumerator ________________________Date _____________ Code_________

Name of Respondent ________________________ Date _____________ Code _________

Wereda:__________________ Kebele __________________

Part A: Household Roster

1. Village Name____________________
2. Sex of the household head 1= Male 2= Female
3. Age of HH __________________
4. Religion, Marital Status and Educational Status of Household Head (refer to the below table).

Religion HH	Marital Status	Educational Status	Responsibility in the community
1=Christian orthodox	1=Married	1= illiterate	1=member of the community
2= Muslim	2=divorced	2= Capable of reading and writing	2= religious leader
3=Protestant	3=Widowed	3= Highest Grade attended (1, 2, 3,4,5,6,7,8,9,10)	3=coordinator of community development work
4=Wakefeta	4=not married	Diploma and above	4=Kebele Administrator
5=other			

5. Size of family members

No	Name of the HH members	Relationship (see code C)	Sex	Age	Education (see code A)	Average working hours per day			Occupation (see code B)
						On farm activities	Off-farm activities	Non-Farm activities	
1									
2									
3									
4									
5									
6									
7									

Code for education, occupation, and relation to head of house head					
Level of education	*Code A*	*Types of occupation*	*Code B*	*Relation to household head*	*Code C*
Illiterate	*1*	*Farming*	*1*	*Wife*	*1*
Read and write	*2*	*Trade*	*2*	*Husband*	*2*
Grade 1-4	*3*	*Hand craft*	*3*	*Son*	*3*
Grade 5-6	*4*	*Blacksmith*	*4*	*Daughter*	*4*
Grade 7-8	*5*	*Casual Labor*	*5*	*Close relatives*	*5*
Grade 9-10	*6*	*Gov't employee*	*6*	*Dependent*	*6*
Grade 11-12	*7*	*Other*	*7*	*Hired labor*	*7*
12+1	*8*			*others*	*8*
12+2	*9*				
College diploma/certificate	*10*				
others	*11*				

6. Are there any children less than 18 years old from other families living in your house because of one or both of their parents has been died? 1. Yes 2. No

Part B: Group Membership

7. Are you or any member of your family an active member of this [GROUP]?	Yes	No
Climate Innovation Platform (CIP)		
Agricultural producer's group (including marketing)		
Livestock producer's group (including marketing)		
Water users' group		
Watershed management group		
Forest users' group		
Tree Nursery Group		
Credit or microfinance group		
Mutual help or insurance group		
Iddir (burial society)		
Iqub (rotating savings group)		
Trade and business association		
Religious group		

Part C: Household land ownership

8. Do you have your own farmland 1. Yes 2. No

9. If your answer for question 8 is yes, would you tell us land holding & farm characteristics of your land?

No	Types of land use	Area (ha)
1	Cultivated (farm) land	
2	Grazing land	
3	Homestead land	
4	Forest land	
5	Unused land(fallowing)	
6	Irrigated land	
7	Total land holding	

10. What is the current number of parcels/plots of farmland of the household? ________.

11. Would you tell us about the characteristics of your farm plots (relief situation, soil type according to local naming, and fertility status)?

Plot Identification	**Relief (topography)** 1. plain 2. moderate 3. sloping	**Soil**	
		Type 1 Black 2. Red 3. Brown 4. Grey	**Fertility status** 1. poor 2. moderate 3. fertile

12. Do you think that your piece of land is enough to support your family? 1) Yes 2) No

13. If no, state your reasons (multiple answers possible)

1= Infertility of land	2=Small size of land
3= Lack of agricultural inputs to increase productivity	4= Large family size
5= Others (specify	

14. Has your farmland size decreased or increased since you start farming?
    1. Increased 2. Decreased 3. No change
15. Is there any change in productivity of the cultivated land? 1= Increased 2= Decreased 3= No change
16. If your answer for question No.15 is increased (1), what are the reasons for the increment of your cultivated land productivity? ***Multiple answers are possible***
    a. Increased soil fertility
    b. Strong extension service (improved seed supply, agrochemical use, and organic fertilizer)
    c. Suitable weather conditions
    d. soil and water conservation practices

17. What are the main constraints to your farmlands? Identify the four main bottlenecks according to order of importance ***Multiple answers are possible.***

1= Land degradation/soil erosion	5=Drought/ Water scarcity	**Rank**
2= Lack of timely input supply	6= Pests and Crop diseases	1st
3=lack of oxen	7= Waterlogging	2nd
4=. Rainfall variability	8=High concentration of stones on the topsoil	3rd
9=salinity	10=highly sandy	4th

18. Which measure(s) do you practice to minimize soil erosion on your own farm, and in your community at large and to increase the productivity of the cultivated land?

Land conservation activities (List types modern, Biological and cultural)	Individually (1=Yes, 2=No)	In group (communally) (1=Yes, 2=No)	NGOs	Status of Protection 1.V/good 2. Good 3.Fair 4.Poor
1. Check dame				
2. Stone Band				
3. Soil Band				
4. Trench				
5. Cut-off drain				
6. fannyaj				
7. Area closure				
8. Terracing				
9. Others, specify				

19. Prioritize the following modern land degradation protection methods based on their problems and challenges.

Types of problems	**Stone Band**	**Soil Band**	**Check Dame**	**Cut-off Drain**	**Fyennajue**
Being Mouse Production					
Reduces Farm Size					
Difficulty during plowing to turn oxen					
Needs high power					
Impracticable					

Part D: Crop Production

20. How many hectares did you farm last production season? _______Timad
21. What is the size of your land with improved soil and water conservation Practices in Timad?
22. Do you practice crop rotation in your locality? 1. Yes 2. No
23. What cropping patterns do you use in your farm land? 1) Mono cropping 2)Mixed cropping 3)Both 4) Other, if any ____
24. Do you use conservation tillage practices? 1. Yes, 2. No
25. Would you tell us the size of farmlands and crops production you harvested during the *belg* season of 2006 E.C.?) And *meher* season 2007 E.C.)?

S/N	**Crop type**	2006 E.C		2007 E.C			
		Belg season		Meher season			
		Farm Size (Timad)	Amount harvested(Kuntal)	Farm size (Timad)	Amount of harvested (Kuntal)	Total quantity sold in Kuntal	Income earned from sale of crops (Birr)
1	Wheat						
2	Barley						
3	Teff						
4	Maize						
5	Sorghum						
6	Horse bean						
7	Peas						
8	Chickpeas						
9	Lentils						
10	Other						

26. Tell us about your perennial crops, fruits and vegetables and the income you earn from them.

S/N	**Crop type**	Number/Stand (Kg)	**Monthly Income (Birr)**	Annual Income (Birr)	**Annual amount of expense for a crop (Birr)**
1	Chat				
2	Coffee				
3	Papaya				
4	Eucalyptus				
5	Onion				
6	Red pepper				
7	Banana				
8	Mango				
9	Zytuna				
10	Carrot				
11	Tobacco				

27. Which modern farm inputs do you apply in order to augment/boost the yields and production of your field and garden crops?

	Input	Use 1=yes 2=no	Amount used (KG)
1	Chemical fertilizer		
2	Improved seeds		
3	Herbicides		
4	Insecticides		
5	Irrigation		
6	Manure and mulch		
7	Compost		

Part E: Livestock Ownership

28. What type of livestock you own and what are their number?

Type of animal	Size in number		Status of Health (**CODE ‘A’**)	Their feeding source (***CODE ‘’B’’***)	Problems related to the fodders (***CODE’C’***)	Income earned from sale of livestock (Birr)
	Improved	Local				
Ox						
Cow						
Sheep						
Goat						
Horse						
Mule						
Donkey						
Poultry						
Bee colony						
Camel						
Other						

Health Status	Code A	Source of fodder	Code B	Problems	Code C
Excellent	1	own private grazing land	1	Shortage of grazing land	1
Very Good	2	communal grazing land	2	High cost of fodder	2
Good	3	crop residue	3	Shortage of supply of fodder	3
Bad	4	buying fodder	4	Lack of improved varieties of fodder	4
		other, please specify		Other (specify)	

29. Why did you sell livestock this year?
    a) To avoid drought risk /disposal of animal
    b) For purchasing food
    c) For buying cloth
    d) Purchasing other consumer goods
    e) Other (specify) ____
30. Which of the followings are the constraints to rearing livestock? Identify the three most important bottlenecks according to order of importance.

S/N	**Constraints**	1=yes 2=no	Rank
1	Shortage of grazing land		
2	Lack of additional fodder		1st
3	Disease prevalence		
4	Lack of sufficient veterinary services		2nd
5	Shortage of water		
6	Attack by wildlife		3rd
7	Recurrent severe drought		

Part F: Access to Information

31. Would you tell us types and sources of information you used?

Information types	Do you have access to information on [type]? 1 Yes 2 No	Please list the main sources of information you received (See Code A)	Were you able to use this information? 1 Yes 2 No	How did you use this information? (see code B)	Why were you not able to use this information? (see Code C)
1.Forecast of extreme events (e.g. drought, flood)					
2.Forecast for the start of the rains (seasonal forecast)					
3. Information on climate change					
4. Information on crop production and management					

5. Information on livestock production and management					
6. Information on tree management and agroforestry					
7. Information on marketing of crop/livestock products					
8. Information on Natural Resource Management					

Codes for Part F

Code A (Source)	**Code B (How do you use)**	**Code C (Why information is not Used)**
1 –Government Extension Workers	1. Changed land management	1 - Found the advice in the past to be unsuitable or unhelpful
2 - NGOs	2 - Changed Crop type	2 - Not interested in changing production practices
3- Community Meetings	3 - Changed Crop variety	3 - Cannot access credit to make changes
4 -Farmer Organizations	4 - Changed fertilizer/pesticides	4 - Do not want to purchase inputs
5- -Research Stations/Researchers	5 - Used of manure/compost/mulch	5 – Advice was received too late in the season to make a difference
6 - Agri-service providers	6 - Changed land size cultivated	6 - Did not provide enough information
7 -Family Members	7 - Changed field location	7 - Not enough labor to make suggested changes
8-Neighbors/friends	8 - Changed timing of activities	8- Changes are too risky
9 -Radio	9. Implemented Soil and water conservation activities	
10 -TV	10 - Started irrigating	
11 - Religious Groups	11 – Used water management	
12-Schools/Teachers	12 - changed livestock type	
13- Indigenous Knowledge	13 – changed feed management	

Part G: Technology Adaptation

32. Having perceived changes in temperature and rainfall, did you under take adaptive measures?
    1. Yes 2. No

practices	Do you currently use [practice] on your farm? 1 Yes 2 No	Why did you adopt this [practice]? See code A	What are the major constraints preventing you from adopting [practice]? See code B
Improved Crop Varieties			
Recommended Fertilizer Application Techniques			
Intercropping			
Water Harvesting			
Agroforestry			
Degraded Land reclamation			
Building Terraces			
Row planting			
Crop Rotation			
Small Scale Irrigation (Vegetables, Seedling Production)			

Code A

Reason For Adopting	
Improved productivity	1
Improved soil fertility	2
Reduced risk of drought	3
Reduced risk of flooding	4
Improved household nutrition or food security	5
Increased income	6
Reduced household labor	7
Reduced soil erosion	8
Improved water retention	9
Diversified income sources	10
Reduced crop loss	11

Code B: Constraints for not using Technology

I have no information	1
Lack of access to credit	2
Lack of access to training	3
Lack of labour	4
Lack of access to improved inputs	5
Lack of markets to sell production	6
Lack of secured land tenure	7
Practice is at odds with cultural practices	8

Part H: Credit and Saving

33. Do you have access to credit services from any saving and credit institutions? 1) Yes 2) No

34. If yes, can you tell the purpose, source and amount of credit you received?

No.	**Purpose of credit**	Yes or no	**Source of credit**	Yes or no	**Amount of credit received (Birr)**
1	For purchasing fertilizer		Relative		
2	For purchasing improved seeds		Traders		
3	For purchasing chemicals		Bank		
4	For purchasing oxen		NGO		
5	For purchasing farm implements		Micro finance institution		
6	For land rent-in		Friends		
7	For other purpose (Specify).		Saving and credit associations		

35. Why were you not able to borrow from [SOURCE]? 1. Inadequate collateral 2. Bad credit history 3. Have outstanding loan 4.Past history of default with lender 5. No reason given.
36. Was credit received adequate and timeliness? 1) Yes 2) No
37. Does any household member (male or female) currently have any savings? [This includes savings at home, bank, shop, friends/relatives, or any other place]? 1) yes 2) No
38. What is the total amount of saving you have from all saving places? |____________|

Part I: Market

39. What is the distance to main market from your home (in walking hours)? ______
40. Are you a member of farmers' cooperative? 1=Yes, 2= No
41. Is there any market linkage for selling your product? 1=Yes, 2=No
42. Do you think that the price you get for your products is adequate? 1. Yes 2. No

Part J: *Non-farm and Off-farm employment opportunities: financial capital*

43. Do any of your household members work in Non-farm activities apart from crop production and livestock rearing? 1. Yes 2. No
44. If yes, would you tell us about the types of activities, amount of income from the job, and the purpose for which you use the money?

Activity type	Estimated annual income from the job		Cash equivalent	Earning used for
	Cash	Kind		
Trade				
Pottery				
Tanning				
Wavering				
Selling fuel wood				
Daily labor				
Jewellery and Welding				
FFW				
Government employee				

Other specify				
Total income from non-farm				

45. Do any of your household members work in Off-farm activities apart from crop production and livestock rearing? 1. Yes 2. No

46. If yes, would you tell us about the types of activities, amount of income from the job, and the purpose for which you use the money?

Off-Farm Activity type	Estimated annual income from the job		Cash equivalent	Earning used for
	Cash	Kind		
Wage from working on others farm				
Sales of natural resources (tree, firewood, charcoal)				
Land rent-out				
Renting out of agricultural tools				
Others please specify				
Total income from off-farm				

Part K: Wealth of the Household

47. Do you think that there are poor, middle, and rich people in your community? 1) yes 2) No
48. If yes, what criteria's are often used to differentiate these group of people? 1) number of livestock 2) size of land 3) cash 4) being a leader 5) other specify
49. To which wealth group your household belong? -------------------.
50. How many of each of the following items do you and your household currently own?

ITEM	Number
Fanos, gas medija	
Radio/Tape Recorders	
Bicycles	
Wrist Watches	
Jewellery/Gold	
Phones (fixed and mobile)	
Televisions	
Video Cassette or DVD Player	
Satellite Dish	
Refrigerator	
Electric Mitad	
Motor Vehicle (Car or Truck)	
Tractor	
Motorcycles	
Bajaj	
Stove	
Sewing or Weaving Equipment	

51. What type of house do you own?

Type of house	Yes or No
Made of concrete/bricks/stone and covered with corrugated iron sheet.	
Wooden, mud plastered wall and covered with corrugated iron sheet.	
Wooden, mud plastered wall and thatched (covered with grass)	
Wooden, unplastered wall and thatched	
Other specify	

Part L: Perception about Climate Change

52. Have you noticed any changes in climate over your lifetime? 1 Yes 2 No 3 Don't know

53. How is the condition of the temperature of the day in the past 30 years?
    1. Increasing 2. Decreasing 3. No change/constant 4. I don't know 5. Other, please specify________________
54. What are the local indicators that show the variability/change in temperature through time in your surrounding? Multiple answers are possible.
    a) Frequency of occurrence of drought and floods
    b) Human and animals diseases that has not been seen before
    c) The emergence of new species of animals and plant in your local area
    d) Changes of clothing style of the communities
    e) Degradation/deterioration of rivers through time
    f) Change of animal and plants/crop type (for instance cultivation of Teff and other crop types)
    g) Other, please specify__________

55. How many times drought occurs on average of during the past 30 years? _____
56. How many times flood occurs on average on year bases? ______________________
57. Have you ever faced new type of disease in your residence? 1= Yes 2= No
58. Frequency of extreme drought;
    a) Lower than the year before
    b) Same as the year before
    c) Higher than the year before
59. Intensity of extreme drought;
    a) Normal (stay for short period)
    b) Sever (stay for long Period)
    c) Extremely sever (stay for very long period)
60. How is the condition of rainfall for the last 30 years?
    1. Increasing 2. Decreasing 3. No change 4. Rains are more erratic 5. Rains come earlier 6. Rains come later.7. I don't know 8. Other, please specify___________________________
61. What are the local indicators that show the variability/change in rainfall through time in your surrounding?
    1. Changes in cropping season, 2. Changes in crop types, 3. Changes in productivity, 4. Other, please specify_______________________
62. Frequency of extreme rainfall;
    d) Lower than the year before
    e) Same as the year before
    f) Higher than the year before
63. Intensity of extreme rainfall;
    a) Normal (stay for short period)
    b) Sever (stay for long period)
    c) Extremely sever (stay for very long period)

64. Are you concerned about long-term changes in climate? 1 Not at all concerned 2 Not very concerned 3 Indifferent 4 Somewhat concerned 5 Very concerned
65. If yes, why are you concerned? (List 3 most important reasons)

1 Reduced agricultural productivity	6 Affect income sources
2 Water scarcity	7 Increase poverty levels
3 Decrease in livestock fodder	8 Food insecurity
4 More soil erosion	9 More natural disasters
5 Health risks	10. Other, Specify_____

66. Perceived effects of climate variability and change on agricultural production and management by farmers

Observed effects of climate variability and change	**Yes or No**
Reduced crop yield	
Partial or total crop failure	
Shortened length of the growing season	
Shift in cropping calendar (delayed planting date)	
Change in crop varieties	
Increased pest and disease prevalence	
Soil erosion	
Land use/land cover change	
Shortage of feed and water availability for livestock	
Reduced livestock	
Other Specify	

67. How well informed do you feel you are about changes in climate and the impacts on your livelihood?

1. Not at all informed	4. Well informed
2. Not very informed	5. Very well informed
3. Averagely informed	

Part M: Climate Change Adaptation

68. If you have observed or believe you will be affected by climate change, have you made any changes to protect yourself, your family, or your community? This can include any agricultural, livestock or livelihood changes. 1 Yes 2 No

69. If your answer for question 68 is yes what changes have you made to deal with environmental stress?

Crop production adjustment	Yes or No	**Livestock adjustments**	Yes or No	**Livelihood diversification**	Yes or No	**Group-based adaptations**	Yes or No
Change crop variety (drought tolerant, pest resistant, fast maturing, high yielding)		Increase the number of livestock		Mix crop and livestock production		Plant indigenous crops	
Change crop type		Decrease the number of livestock		Change from livestock to crop production		Increase planting of trees	
Crop diversification							

Change planting dates		Diversify livestock feeds		Change from crop to Livestock		Construct earth dams	
Increase amount of land under production		Change livestock feeds		Seek off farm employment		Protect springs	
Decrease amount of land under production		Move animals to another site		Receive training in other livelihood activities		Start-up tree nurseries	
Implement soil and water conservation		Conserve fodder /crop residue for dry years		Members of the household migrate to an urban area			
Agroforestry Practice				Members seek casual or contracted agricultural employment			
Increase fertilizer applications							
Decrease fertilizer applications							
Build a water harvesting scheme							
Build a diversion ditch							
Use more water for irrigation							
Crop rotation							

70. If no, why have you not made any changes? ***'Multiple answer is possible***

1) Don't see the need to make changes	7) Think that the practice (or change) might fail or not work
2) Don't know what to do	8) Materials not available (e.g. water for irrigation, materials for mulching)
3) Not enough money to implement changes	9) Requires special tools
4) Not enough labour to implement changes	10) Changes not appropriate for soil type or landscape
5) Inputs not available for purchase at the market	11) Changes at odds with cultural practices
6) Need to see if being practiced by neighbours' first	12) Land is being used by more profitable activity
	13) Not enough information about climate change
	14) lack of effective early warning system

Part N: Infrastructures

71. What is the distance to the following infrastructure?

Type of infrastructure	Distance form your home in Walking Hours
What is the distance to all- weather roads from your home (how long does it take	
What is the distance of your home to the nearest school (how long does it take	
What is the distance to Health services from your home?	
What is the distance to Veterinary services from your home?	
What is the distance to water source from your home?	
What is the distance to saving and credit institutions?	
What is the distance to market from your home?	

Part O: major components for Livelihood Vulnerability Index (LVI)

Health

72. How long does it take you to get to a health facility? -----------------
73. Is anybody in your family chronically ill (they get sick very often)? 1. Yes 2. No
74. Has anyone in your family been so sick in the past 2 weeks that they had to miss work or school? 1. Yes 2. No
75. Which months of the year is malaria particularly bad? How many mosquito nets do you have? ----

Social Networks

76. In the past month, did relatives or friends help you and your family: (e.g., Get medical care or medicines, Sell animal products or other goods produced by family, Take care of children) 1. Yes 2. No
77. In the past month, did you and your family help relatives or friends: (same choices as above) 1. Yes 2. No
78. Did you borrow any money from relatives or friends in the past month? 1. Yes 2. No
79. Did you lend any money to relatives or friends in the past month? 1. Yes 2. No
80. In the past 12 months, have you or someone in your family gone to your community leader for help? 1. Yes 2. No

Food

81. Where does your family get most of its food? 1. Own production 2. Purchased 3. Aid 4. Others (specify)----------------------
82. Are there times during the year that your family does not have enough food? 1. Yes 2. No
83. If your answer for question number 82 is yes, how many months a year does your family have trouble getting enough food? ------------
84. Does your family save some of the crops you harvest to eat during a different time of year? 1. Yes 2. No
85. Does your family save seeds to grow the next year? 1. Yes 2. No

Natural disasters and climate variability

86. How many times has this area been affected by a flood/drought in 1976–2007 E.C? (for the last 30 years)---------
87. Did you receive a warning about the flood/drought before it happened? 1. Yes 2. No
88. Was anyone in your family injured in the flood/drought? 1. Yes 2. No
89. Did anyone in your family die during the flood/drought? 1. Yes 2. No

Part P: Food Security

90. Were there months, in the past 12 months, in which you did not have enough food to meet your family's needs? 1) yes 2) No
91. If yes, how many months in the past 12 months during which you did not have enough food to meet your family's needs? And which months?
92. Has your household been receiving remittances? 1. Yes 2. No
93. If you have received remittances, would you tell us about the source, the relationship you have with the person/organization who remitted you, the average amount in cash or kind per annum, and the purpose for which you use the remittance?

Amount per annum		**Use of the remittance**
Cash	kind	
		1. for building a house 2. for purchasing ox 3. for buying food 4. for buying clothes 5. for purchasing farm Implements 6. for purchasing inputs 7. for petty trading 8. others, specify

94. Have you ever received relief support this year? 1. Yes 2. No

95. If you have had an opportunity to receive relief support, would you specify the amount of support in 2007 E.C?

Type of support	**In 2007 E.C**	
	type	amount
Free hand-out		
FFW		
Cash for work		
	1. wheat 2. maize 3. oil 4. cash	kg/birr

96. Do you meet the all-year round food requirements of your household members from own production? 1. Yes 2. No
97. If no, how do you fill the gap?

Source of grain	**Type and amount of grain obtained**
Remittance	
PSNP	
Food -Aid	
Fire wood sale	
Charcoal sale	
Farm animal sale	
Working on others farm	
Land rental	
beginning	
Eating taboo food items	
Other sources specify	

98. If you are not self-sufficient, for how many months do your own productions cover the food requirement at home? (mention name of months)____________________________
99. Does the income you earn from non-farm activities enable you to buy food for bridging the deficiency? 1. Yes 2. No
100. According to your own self-assessment, is your household: 1. food secure 2. Food insecure 3. Varies from one year to another 4. do not know
101. What do you think are the main reasons for being food insecure?

Reason for food insecurity	1. Yes 2. No
Inability to produce sufficient grains and to rear livestock	
Inadequate income from non-farm activities	
Instability due to frequent changes in rural policies	
Failure to properly utilize own production and other earnings	
Other specify	

102. What have been the main constraints to expanding your crop production, as well as for keeping sufficient numbers of stock in order to become self-sufficient in food all year round?

s/n	Constraints	1. Yes 2. No	Three most important Bottlenecks		
1	Drought		1st	2nd	3rd
2	Frost				
3	Waterlogging				
4	Pest and diseases				
5	Erratic rainfall distribution				
6	weeds				
7	Shortage of farm oxen				
8	Poor storage				
9	Insufficient land holding				
10	Poor soil fertility				
11	Lack of access to appropriate technology				
12	Limited know-how and skills				
13	Inadequate extension services				
14	Dependency on rain-fed farming				
15	Failure to utilize irrigation				
16	Lack of access to post-harvest technology				

103. **Consumption expenditure for the last 12 months**

Food type	Consumed from purchased	
	Amount (kg)	Value (birr)
Cereals and pulses		
Wheat		
Teff		
Maize		
Barely		
Bean		
Pea		
Chick pea		
Others (Specify)		
Fruits and vegetables		
Cabbage		
Potato		
Tomato		
Onion		
Banana		
Orange		
Others (specify)		
Animal products		

Butter		
Cheese		
Milk		
Meat		
Other		
Salt		
Sugar and oil		

104. **Non Food Expenditure in the last 12 months.**

Item	**Expense (in Birr)**
Clothing (dress and foot wear)	
House rent	
Water expense	
Transport and communication	
Entertainment (visit of relatives)	
Education	
Health care	
Religious& cultural expense	
Animal health expense	
Gas and Other fuel	
Beverages and cigarette	
Government tax	
Social expenses	

Thank you Very Much for Your Kind Responses!!