AGROECOSYSTEM BASED CLIMATE VARIABILITY & CHANGE VULNERABILITY & ADAPTATION ANALYSIS, AND EROSION HAZARD ASSESSMENT IN FINCHA'A SUB BASIN, BLUE NILE BASIN, ETHIOPIA

Israel Tessema Lewte

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

Presented in 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 2019

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Advisor: Belay Simane (Ph.D., Associate Professor)

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DECLARATION

I, the undersigned, declare that this thesis entitled *Agro-ecosystem based Climate Change vulnerability and adaptation analysis, and Erosion Hazard Assessment in Fincha'a Sub-basin; Blue Nile Basin, Ethiopia* is my original work and has never been submitted at any University, for any degree or other purposes.

Name: ________________________________

Signature: ________________________________

Date: ________________________________

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

Supervisor name: ______________________________

Signature: ___________________________________

Date: ______________________________________

DISSERTATION APPROVAL
ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES

This is to certify that the thesis prepared by Israel Tessema entitled: *"Agro-ecosystem based Climate Change vulnerability and adaptation analysis, and Erosion Hazard Assessment in Fincha'a Sub-basin, Blue Nile Basin, Ethiopia"* and submitted in fulfillments for the requirements for the Degree of Doctor of Philosophy (Environment and Development) complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

Signed by the Examining Committee:

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Chair of Department or Graduate Program Coordinator	Signature	Date

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LIST OF ORIGINAL PAPERS

This dissertation is based on the following four original papers, which are listed from I –IV.

I. Accepted as Israel Tessema and Belay Simane. Agro-ecosystem analysis of Fincha'a sub-basin, Blue Nile River Basin, Ethiopia. *Journal of Tropical and Subtropical Agroecosystem*.

II. Published as Israel Tessema and Belay Simane, 2019. Vulnerability Analysis of Smallholder Farmers to Climate variability and Change: An Agro-ecological system Based Approach in the Fincha'a Sub-basin of the Upper Blue Nile Basin of Ethiopia. *Ecological Processes* DOI https://doi.org/10.1186/s13717-019-0159-7

III. Under Review as Israel Tessema and Belay Simane. Smallholder Farmers' perception and adaptation to climate variability and change in Fincha Sub-basin of the Upper Blue Nile River Basin of Ethiopia. *Journal of Agriculture and Food Security*.

IV. Under Review as Israel Tessema and Belay Simane. Soil Erosion Hazard Assessment for Conservation Planning and Prioritized Action at Watershed Level: The case of Neshe Dam Watershed, Blue Nile River Basin, Ethiopia. *The International Journal of River Basin Management*.

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LIST OF ACRONYMS

ANOVA	Analysis of Variance
AES	Agricultural Ecosystems (Agroecosystems)
AEZ	Agro Ecological Zones
ANSWERS	Areal Nonpoint Source Watershed Environmental Resources Simulation
ASTER	Advanced Space borne Thermal Emission and Reflection Radiometer
BOARD	Bureau of Agriculture and Rural Development
CO_2	Carbon Dioxide
CSA	Centeral Statistical Agency
DDAEPA	Dire Dawa Administration Program of Adaptation to Climate Change
DEM	Digital Elevation Model
EEPC	Ethiopian Electric Power Corporation
EHRS	Ethiopian Highland Reclamation Studies
ENTRO	Eastern Nile Technical Regional Organization
EPCC	Ethiopian Pannel on Climate Change
EUROSEM	European Soil Erosion Model
FAO	Food and Agricultural Organization
FGD	Focus Group Discussion
GDM	Global Digital Elevation Model
GDP	Gross Domestic Product
GHG	Greenhouse Gases
GIS	Geographic Information System
G_tCO_2 eq	Gigatonne Carbon dioxide equivalent
ICRISAT	International Crop Research Institute for Semi-Arid Tropics
IIRR	International Institute of Rural Reconstruction
ILCA	International Livestock Center for Africa
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Inter Tropical Convergence Zone
KII	Key Informant Interviews
KM	Kilometer
LVI	Livelihood Vulnerability Index
Masl	Meter above sea level
MES	Millennium Ecosystem Assessment
MoA	Ministry of Agriculture
MoFED	Ministry of Finance and Economic Development
MoWIE	Ministry of Water, Irrigation, and Electricity
MUSLE	Modified Universal Soil Loss Equation
NAPA	National Adaptation Program of Action
NMA	National Meteorological Agency
NPC	National Planning Commission
PET	Potential Evapotranspiration
RS	Remote Sensing
RSCZ	Red-Sea Convergence Zone
RUSLE	Revised Universal Soil Loss Equation

SCRP	Soil Conservation Research Project
SLM	Sustainable Land Management
TAR	Third Assessment Report
UNDP	United Nation Development Program
UNFCCC	United Nations Framework Convention on Climate Change
USLE	Universal Soil Loss Equation
UTM	Universal Trans-Mercator
WEPP	Water Erosion Prediction Project

ABSTRACT

Agroecosystem based Climate Variability and Change Vulnerability & Adaptation Analysis, and Erosion Hazard Assessment in Fincha'a sub basin, Blue Nile Basin, Ethiopia

Israel Tessema Lewte, Addis Ababa University, 2019

The objective of the study is to analyze the agroecosystems of Fincha'a sub basin and their climate variability and change vulnerability, and to examine how smallholder farmers of the sub basin have perceived and adapted to climate variability and change. The study is based on household and field-level primary data collected from 380 farm households in the Highland, Midland, Wetland (seasonally waterlogged), and Lowland agroecosystems of the Fincha'a sub-basin. The LVI approach framed within IPCC is customized for the agro-ecosystem specific vulnerability analysis and the RUSLE model utilized to study the level of erosion hazard. Primarily, agro-ecosystem analysis conducted in collaboration with experts, development agents, and local communities; and four distinct agroecosystems (Highland, Midland, Wetland (seasonally waterlogged), and Lowland) identified. Then, the identified agroecosystems examined in light of their potential for agricultural production and the challenge presented by climate variability and change. Based on the vulnerability analysis, the study found that the lowland AES exhibited higher exposure, low adaptive capacity, and high vulnerability while the midland AES demonstrated lower exposure, higher adaptive capacity, and lower vulnerability. The wetland and highland AESs scored intermediate results. Investigation of the perception and adaptation strategy of smallholder farmers identified that majority of the community perceived there is climate variability and change. However, the adaptation measures implemented until now are not adequate to meet the impending challenges situate by climate variability and change. The result from the erosion hazard analysis revealed that the potential annual soil loss of the watershed ranges from 0.0 to 350.93 t ha^{-1} $yr^{-1}$and the average annual soil loss for the whole watershed anticipated at 37.54 t ha^{-1} yr^{-1}. Despite significant number of farmers' perceived climate variability and change, the number of farmers adopted certain adaptation measures that minimizes their vulnerability are below average. These necessitate the need for planned interventions to identify and support effective adaptation measures. Furthermore, off-farm, non-farm, and watershed based appropriate soil and water conservation strategies should be enhanced by fostering the enforcement of scientific land use.

Keywords: Agro-ecosystem, Climate changes, Vulnerability, Adaptation, Soil erosion hazard, Watershed

1. GENERAL INTRODUCTION

1.1Background

There is wide scientific consensus that the total greenhouse gases (GHG) emissions have continued to increase over 1970 to 2010 with larger absolute decadal increases toward the end of this period. Despite a growing number of climate change mitigation policies, annual GHG emissions grew on average by 1.0 gigatonne carbon dioxide equivalent ($GtCO_2eq$) (2.2 %) per year from 2000 to 2010 compared to 0.4 $GtCO_2eq$ (1.3 %) per year from 1970 to 2000. Total GHG emissions were the highest in human history from 2000 to 2010 and reached 49 (±4.5) $GtCO_2eq$ / yr in 2010 (IPCC 2014).

Consequently, the GHG emissions are causing global climate changes and the changes in climate have caused impacts on natural and human systems (water resources, agriculture, human health, ecological system and overall economy of the nations) on all continents and across the oceans (IPCC 2014). Experiments and model predictions have shown that climate change through increased atmospheric CO_2 concentration, and the resulting rise in temperatures and changes in rainfall pattern, amount and variability affect crop production negatively in a multi faceted way (EPCC 2015).

Conversely, there are reports that claimed climate change also has positive impacts on agriculture, albeit the negative impact outweighs. The positive impact of climate change on crop production reported through increased carbon fertilization especially in C3 photosynthetic pathway species in some low-temperature regions. In C3 plants, increased CO_2 concentration increases yield by increasing rate of photosynthesis, leaf area index, and accumulation of non-structural carbohydrates, biomass and decreasing stomatal conductance and transpiration loss of water (Chauhan et al. 2014). You and Ringler (2010) projected 8-10% increase in agricultural GDP of Ethiopia due to fertilization of CO_2 by 2050 if no hydrologic variability compared to the base scenario. On the other hand, elevated CO_2 negatively affects crop production by decreasing the carbon to nitrogen ratio (Chauhan et al. 2014).

Unlike CO_2, elevated temperature affects crop production negatively by increasing rate of respiration; hastening plant growth and development; increasing rate of water loss by increasing evapo-transpiration; and decreasing nutrient use efficiency through increased rate of decomposition and mineralization. Likewise, the increase in rainfall affects crop production negatively in Ethiopian highlands by increasing flooding, water logging, run off, soil erosion and nutrient leaching. Contrarily, decreasing rainfall affects crop production by creating water deficit conditions (EPCC 2015).

Specifically, the predicted changes in temperature and rainfall patterns substantially affect the potential of agricultural production. The impact on agriculture observed irregularly distributed across the regions and level of economic development. The low-laying areas and developing countries are suffering a lot and affected more adversely than others affect by climate variability and change (Stern 2007; IPCC 2014). Recent estimates show that if measures to abate global warming are not carried out, global agricultural productivity will reduce by 15.9 percent by the 2080s, with developing countries experiencing a disproportionately large decline of 19.7 percent (Cline 2007).

Africa is considered the most vulnerable and extremely affected region in the world in terms of climate change. Low level of irrigation practice, high population pressure on natural resources, increasing land degradation, and low levels of adaptation capacity are some of the features of African farming (FAO 2010a). The contribution of agriculture to the gross domestic product in Africa is far higher than in developed regions. Possibly this is evident nowhere more than in sub-Saharan Africa, where the economy of the nations are enormously dependent on agriculture and any shock happened in this sector will affect their economy badly.

Like other sub-Saharan African countries, Ethiopian economy is typically driven by agricultural sector despite the issue of high rainfall variability that leads to frequent drought, severe land degradation (especially in the highland region), and poor land management practices (Diao & Pratt 2007; World Bank 2010; Conway & Schipper 2011; EPCC 2015). The sector contributes about 38.5% of the Gross Domestic Product (GDP), 85% of the employment, 90% of the export earnings, and 80.2% of the populations' earnings coming from this sector. It is also the major source of food for the population and hence the prime contributing sector to food security (World Bank 2008; MoFED 2010; Central Statistical Agency [CSA] 2013; National Planning Commission 2016).

However, this sector has been threatened and being affected by climate variability and change. Study conducted by the National Meteorological Agency of Ethiopia (NMA 2007) revealed that, there has been a warming trend in the annual minimum temperature over the past 55 years and it has been increasing by about 0.37 ^{0}C every ten years. The trend analysis for rainfall in the report showed that though annual rainfall remained more or less constant when averaged over the whole country, there was a very high variability of rainfall over the past years. Similarly, study conducted by EPCC (2015) shows in the last 50 years; the average annual minimum temperature has shown an increasing trend of 0.2^{o}C per decade. The nation's rainfall characterized by seasonal and inter-annual variability (Conway 2000; Seleshi and Zanke 2004; Kindie et al. 2016). The annual rainfall variability in most part of the country remains above 30% (Kindie et al. 2016).

According to the National Adaptation Program of Action (NAPA), the foremost-predicted impacts of climate change on Ethiopia's agriculture include dry spells and frequent droughts, reduced growing season, and increased occurrence of pests and diseases (NMA 2007). The same report also identifies drought and floods are the two major weather extreme events in the past, currently and in future climate of Ethiopia, and agriculture and food security are the sectors impacted most. Ethiopia frequently cited as a country that is highly vulnerable to climate variability and change. A major underlying vulnerability factor is the heavy dependence of the economy on climate sensitive rain-fed agriculture system (World Bank 2010; Conway & Schipper 2011; EPCC 2015; Arragaw & Woldeamlak 2016; Paul & Weinthal 2018).

Furthermore, as different studies have shown, smallholder farmers in different parts of Ethiopia are facing different climate variability and change related problems. Such problems include reduced or variable rainfall, warming of temperatures, change in length of growing seasons, crop and livestock pests and diseases, weed problems, flooding, shortage of water and land degradation (Woldeamlak 2012; Wagesho et al. 2013; Arragaw & Woldeamlak 2017). The impact of climate variability and change contributes to reduced agricultural productivity, and without sound adaptation strategies by farmers, jeopardized the future sustainability of the sector (Arragaw & Woldeamlak 2016).

There are also different studies conducted by different scholars and institutions to know the vulnerability and adaptation strategies of Ethiopian farmers to climate variability and change. Some of these studies were carried out a national level like Dercon (2004); Dercon et al. (2005); NMA (2007); Conway & Schipper (2011); Mahoo et al. (2013); and Kindie et al. (2016). Others like MoFED (2008), Deressa et al. (2008); Woldeamlak & Dawit (2011); Kassie et al. (2014) and Getachew et al. (2018) studied the vulnerability and adaptation strategies at regional and agroecological levels.

Besides, there are other site-specific studies conducted in different parts of the country as study conducted by Simane et al. (2014) in the tropical highland region of Ethiopia, Choke Mountain, by using the Livelihood Vulnerability Index adapted to the IPCC framework (LVI-IPCC). Similarly, different authors used the same framework with some modification to major components to resemble the local context in Ethiopia (Asrat and Simane 2017; Amare and Simane 2017; Chala et al. 2017). The methodology has a capacity to identify the socio-economic and biophysical factors that define the vulnerability of a community (Hahn et al. 2009). Since climatic and biophysical conditions change so dramatically over short distances in the Ethiopian highland regions and other similar tropical highland regions, it creates a challenge for policy relevant implementation of the LVI-IPCC framework in all places of the nation (Simane et al. 2014).

Consequently, this particular study selected Fincha'a sub basin because it is expressed as one of the erosion hot spot and vulnerable areas of the Blue Nile river basin of Ethiopia (MoWIE 2014). In addition, the sub-basin is one of the least researched parts of the Blue Nile River Basin in terms of climate variability and change. Furthermore, preliminary assessment made in the sub basin confirm that climate change and non-climatic drivers induced land degradation problems causeing multiple impacts leading to a decline in productivity and caused a challenge on the adaptive capacity of the smallholder farmers to climate related hazards.

Thus, it is imperative to understand the nature of climate variability and change induced perception, vulnerability and adaptation of the community by using a cross sectional data set collected from different agroecosystems (AES) within the sub basin. The relevance of AES-based generalization to household-level analysis allows us to map vulnerability profiles across the sub-basin. The rationale behind for mapping agroecosystem as a unit of analysis is because AES is an intersection of a set of agriculturally relevant climatic factors; soils and physiographic variables relevant to crop production; and a prevailing set of cropping practices. It is also important for adaptation planning and allows decision makers to understand patterns of vulnerability across relatively broad geographical locations.

1.2 Statement of the problem

It is predicted that climate variability and change will increase, characterized by heightened frequency and intensity of extreme weather conditions in Africa (Nhemachena & Hassan 2007; IPCC 2014). Projected rainfall change over sub-Saharan Africa in the mid- and late 21st century is uncertain. In regions of high or complex topography such as the Ethiopian Highlands, downscaled projections indicate likely increases in rainfall and extreme rainfall by the end of the 21st century (IPCC 2014). Among the many challenges constraining Ethiopian agriculture, none is more severe than that caused by its overwhelming dependence on the vagaries of weather and climate (EPCC 2015).

Currently it is apparent that climate variability and change for Ethiopia is looming. It is causing significant damage to life, property, natural resources and economy in Ethiopia; making the most important economic systems highly vulnerable (EPCC 2015). Apart from its direct impact on the agricultural sector of the country, it is worsening the already widespread land degradation problem of the country especially in the highland parts of the country by its climate extreme events (Mengistu et al. 2014). Studies have shown that flood hazard is increasing in the highland areas due to changes in land use/land cover, rainfall pattern, and drainage (Kassa 2014). In 2006 alone flood claimed 719 human lives, displaced over 241,699 people, severely damaged infrastructures and houses, and caused property loss worth million USD across the country (Tadesse and Dagnachew 2006; DDAEPA 2011).

Generally, Ethiopia is vulnerable to climate variability and change and the change is likely to increase the frequency and magnitude of natural disasters and extreme weather events (FAO 2010a). The country's subsistence agriculture, being the source of livelihood for the large majority of the population, is particularly vulnerable to climate variability and change as smallholder farmers have inadequate resources to adapt to the change (Simane et al. 2014).

Consequently, Ethiopia is confronted with the challenges of feeding its population. Food insecurity and pervasive poverty typify the country in the face of climate change as this devastates the livelihood of significant portion of the population (FAO 2014).

Correspondingly, different scholars tried to conduct study on vulnerability and adaptation to climate change in different parts of Ethiopia to investigate the determinants and maximize the responses for climate change impacts (Dercon et al. 2005; Deressa et al. 2008; Woldeamlak 2012; Simane et al. 2014; Asrat and Simane 2017; Amare and Simane 2017; and Chala et al. 2017). However, vulnerability and adaptation is place-and context-specific (IPCC 2014). Thus, the information obtained from previous studies was not sufficient to represent the study area, as site-specific issues require site-specific knowledge.

Moreover, most studies like (Woldeamlak 2012; Asrat and Simane 2017; Amare and Simane 2017; and Chala et al. 2017) focused on different agro-ecologies with different social, institutional and ecological settings. Similarly, a study conducted by Deressa et al. (2008) has assessed vulnerability to climate change and adaptation responses using region as one unit of analysis. However, within the region there is a great variation from one agroecosystem to the other in terms of socio-economic and environmental circumstances. Thus, such kind of studies does not represent the agroecosystem level vulnerability. Furthermore, the type and role of various adaptation strategies and practices, and the adaptive behavior of households at different agroecosystem is not well addressed. Therefore, this particular study wants to capitalize the variation among agroecosystems in terms of vulnerability and adaptation strategies in the sub basin.

Likewise, there are gaps in the methodology applied in some of those studies. While most studies of vulnerability like Simane et al. (2014), Asrat and Simane (2017), Amare and Simane (2017), and Chala et al. (2017) assessed the vulnerability to climate variability and change based on subjective assessment, this study utilized both subjective and objective (erosion hazard) based assessment of vulnerability to climate variability and change. Similarly, Deressa et al. (2008) has assessed vulnerability to climate change and adaptation responses only using quantitative approaches. However, both qualitative and quantitative approaches have strength and weakness, to benefit from the strengths of both approaches this study employs mixed method approaches.

Hence, there are gaps in the study areas covered, unit of analysis employed and the methodologies applied.

In Fincha Sub-basin (the focus of this particular study), like other parts of the nation, the population is growing rapidly. The rapid increase in population requires the need for additional resources like land for sustaining the livelihood of additional population. Conversely, different development activities which are land and water intensive in nature, are carried out and being implemented by the government of Ethiopia in the sub basin. These development activities include Hydroelectric Power Development and Sugarcane Production and Sugar processing factory.

The increase in population coupled with the land intensive development activities has created and being creating different biophysical and socioeconomic environment problems in the sub basin. Some of the problems to mention are land use land cover change, the Fincha'a Hydroelectric Dam alone inundated a total of 120 km^2 of swamp, 100 km^2 of grazing land, 18 km^2 of cropland and 1.2 km^2 of forest. Apart from the extensive water body, the most important changes in land use were the loss of grazing land and the increase in cropland. Grazing land occupied 555 km^2 in 1957, but only 332 km2 left in 2001. In the same period, the area of cropland went up from 403 km2 to 607 km2, indicating large-scale conversion of grazing land into cropland (Bezuayehu and Sterk 2008). This expansion of cropland in the Fincha'a watershed was much greater than the changes found in several studies conducted elsewhere in Ethiopia, where population growth was the main reason for the observed land use changes.

Because of the conversion of grazing land to cropland, the community of the area is anguishing due to lack of pasture. According to Bezuayehu (2006), livestock numbers have decreased in the area due to the shortage of permanent grazing land and farmers forced to use the swamp as pasture, which frequently results in drowning of animals.

On the other hand, Dechasa (2003) argued that because of the Amarti dam project, other dam constructed in the sub basin to increase the capacity of Fincha'a Hydroelectric power generation, the community in the area nowadays confronted with a decline in crop and livestock production and even recently with famine. Other similar problems that currently surfaced in the area includes decline in agricultural productivity, environmental degradation, deforestation, biodiversity loss, loss of wild animals and soil erosion are some to mention.

On the same token, farmers who have relocated from their farmland because of different development activities that has been carried out within the sub basin like dam construction for hydroelectric power generation had resettled themselves in the hilly areas of the watershed, owning 23% less land and 24% fewer livestock units (Bezuayehu 2006). The resettlement of farmers towards the higher and steeper parts of the watershed may have further aggravated the soil erosion problems, which are a serious problem in the Ethiopian highland areas, threatening the agricultural sector (Hurni 1993) and causing increased sedimentation of reservoirs and lakes.

The other important problem in the sub basin is the problem of land degradation and associated soil erosion. As study conducted by Bezuayehu and Sterk (2008) in Fincha'a watershed, which is part of the sub basin, revealed that the proportion of the watershed exposed to possible maximum soil loss was cropland, amounting to 31% in 1957, 36% in 1980 and 46% in 2001. This shows that the area potentially subjected to accelerated erosion was increasing from time to time.

Moreover, it is apparent that about 90% of Ethiopia's population as a whole and the sub basin particularly derives their livelihood from subsistence agriculture that has already threatened by climate variability and change. The country is prone to droughts, which have become more frequent over the last decades with devastating impacts on food security, health, and environmental degradation. Drought frequency and intensity have rocked the country with further disturbances from the recent phenomena in different parts of the nation (NMA 2007; World Bank 2008; EPCC 2015).

As a result, the impacts of climate variability and change will require management at different levels, namely, mitigation strategies adopted by governments and environmental bodies (specifically to address greenhouse gas emission, increasing adaptive capacity of smallholder farmers, diversifying coping mechanisms and improving the reliability of information for managing climate risks). Farmers have a myriad of practices that help them to overcome the vagaries of the harsh environment and allow them to sustain their livelihoods and actively manage their environment (Scoones et al. 1996; FAO 2010a; EPCC 2015).

The above-mentioned socioeconomic and biophysical problems coupled with the gradual trends of increasing temperature, decreasing precipitation and change in rainfall pattern negatively affect agriculture sector. The climate related risks especially droughts and high rain (floods), natural calamities impoverishing Ethiopian farmers, are also expected to weaken their capability to cope and adapt to long term changes and increases their vulnerability of small holder farmers residing within the sub basin. These is, therefore, a requirement for comprehensive study to understand the vulnerability and adaptive strategies that farmers currently employ and what factors influence these strategies in an attempt to secure their livelihoods.

In this study smallholder farmers (or small-scale farmers), that is, those operating a farm of 2 hectares or less (World Bank 2007) and inhabiting the Fincha'a sub basin will be the focus group of this study. They are among the ones hit by climate variability and change but few comprehensive studies exist which discuss how they adapt to climate change and the various ways that policies and institutions support them in this process.

Thus, in view of the importance of the area and sensitivity of the artificial lakes found within the sub basin this research analyses the various ways that climate change influences of smallholder livelihoods and the actions taken by various actors at different levels to address the threats and opportunities posed by climate change to smallholder agriculture.

1.3Study Objectives and Research Questions

1.3.1 Study Objectives

The general objective of the study is agroecosystems based climate variability and change vulnerability & adaptation analysis of smallholder farmers, and erosion hazard assessment in Fincha'a sub basin.

The study aims to pursue the following specific objectives under this main objective:

- To analyze the agroecosystems found in the study sub basin;
- To assess agroecosystem specific climate vulnerability of the study area;
- To analyze the smallholder farmers' perception and adaptation to climate variability and change in the study area;

- To examine the states of soil erosion in Neshe dam watershed and to prioritize sub-watershed for conservation planning on the basis of erosion risk

1.3.2 Research Questions

The following are key questions that the research tried to address:

1. What are the different agroecosystems that comprise the Fincha'a sub basin and their associated major potential and constraints of each agroecosystem? (Paper I)
2. How different are the agroecosystems in terms of vulnerability to climate variability and change? (Paper II)
3. What are farmers' adaptation responses to perceived climate variability and changes? (Paper III)
4. What is the mean annual rate of soil loss (soil erosion) from the Neshe Dam watershed and which part of the watershed is the main source of sediment to the reservoir? (Paper IV)
5. Which areas of the watersheds need the highest priority for conservation planning to implement the specific measures? (Paper IV)

1.4Significance of the study

This study provides useful empirical information to policy makers, researchers, academicians, development practitioners and other regarding the potentials and constraints of the Fincha'a sub basin agroecosystems, the climate variability and change vulnerability, and the climate change perception and adaptation strategies of smallholder farmers. Moreover, it provides an insight about the erosion hazard found within the sub basin and identifies erosion hot spot areas for conservation planning in Neshe dam watershed. It also provides an agroecosystem specific policy recommendations targeted to smallholder farmers in central highland parts of the country owing to climate variability and change induced factors.

The study also recommends some possible adaptation strategy options potentially implemented by local farmers, development agents and Woreda agricultural experts. Such interventions reduces climate variability and change impacts through enhancing adaptive capacity, increase agricultural productivity and reducing the vulnerability of smallholder farmers and increasing the resilience of the agroecosystems found within the sub basin. Besides, the study pinpointed some gaps and limitations that future studies need to address.

1.5Study Area Description

1.5.1 Bio-Physical Setting of Fincha'a sub-basin

1. Location of Fincha'a sub basin: Fincha'a Sub-basin is one of the sub-basins of the Blue Nile River basin. The Ethiopian part of the Blue Nile River basin includes the Abbay, Tekeze and Baro-Akobo river basins. The Abbay river basin, where the study sub basin is found, has a total surface area of about 199,812 sq km and located in the northwestern region of Ethiopia between 7^0 40' N and 12^0 51' N latitude and 34^0 25' E and 39^0 49' E longitude. The study sub-basin is one of the 16 sub-basins of Abbay river basin and specifically located in the south-central part of the basin, western-central Ethiopia (Figure 1-1).

Specifically, Fincha'a sub-basin located between 9^0 10' N and $10^0$05' N latitude, and $37^0$00' E and $37^0$40' E longitude and has an area of about 4,089.5 km^2. The altitude of the sub-basin ranges approximately between 836 masl, in the lowland of the Abbay gorge located in the northern part of the sub-basin, and 3209 masl, in Guddene mountain of Jima Geneti District. The highlands in the western and southern part of the sub-basin are higher in altitude, greater than 2300 masl up to 3209 masl.

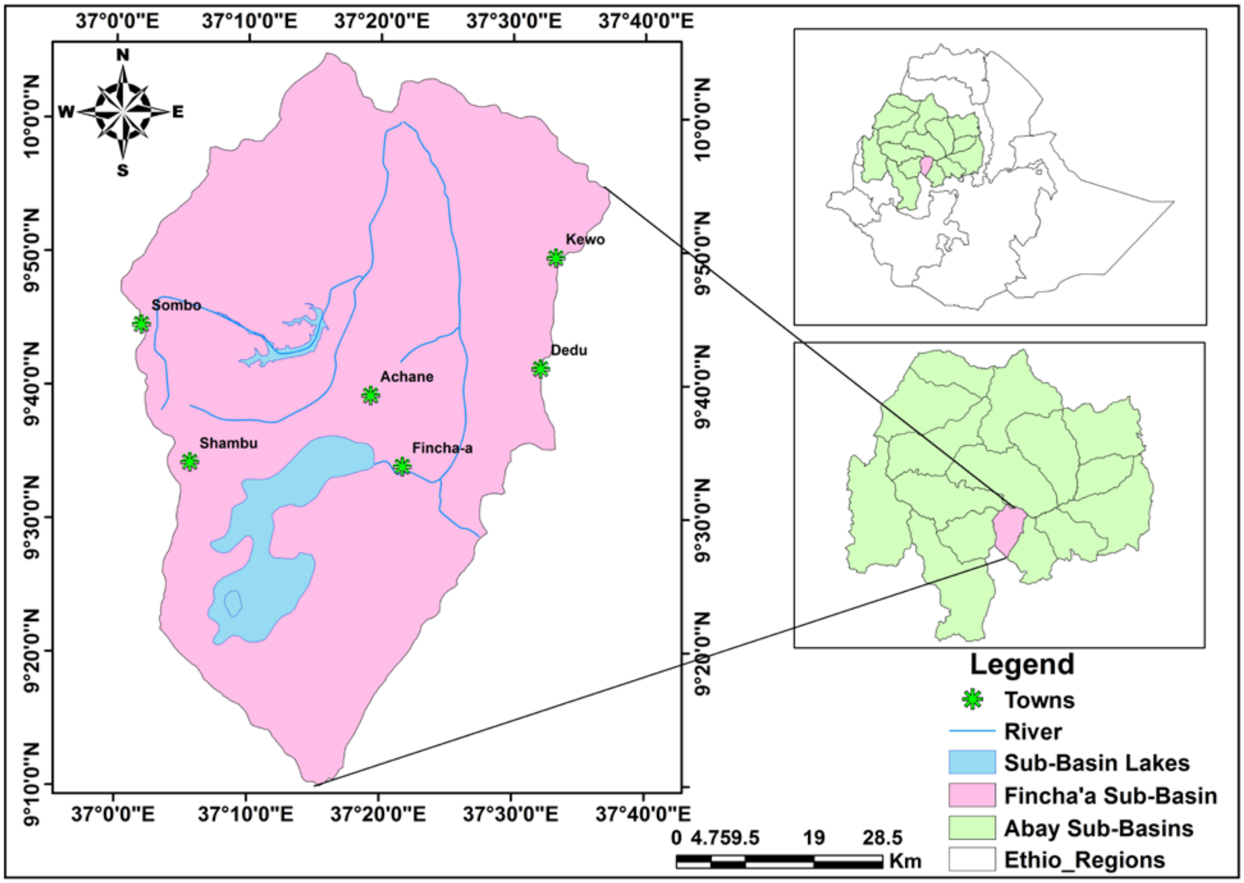


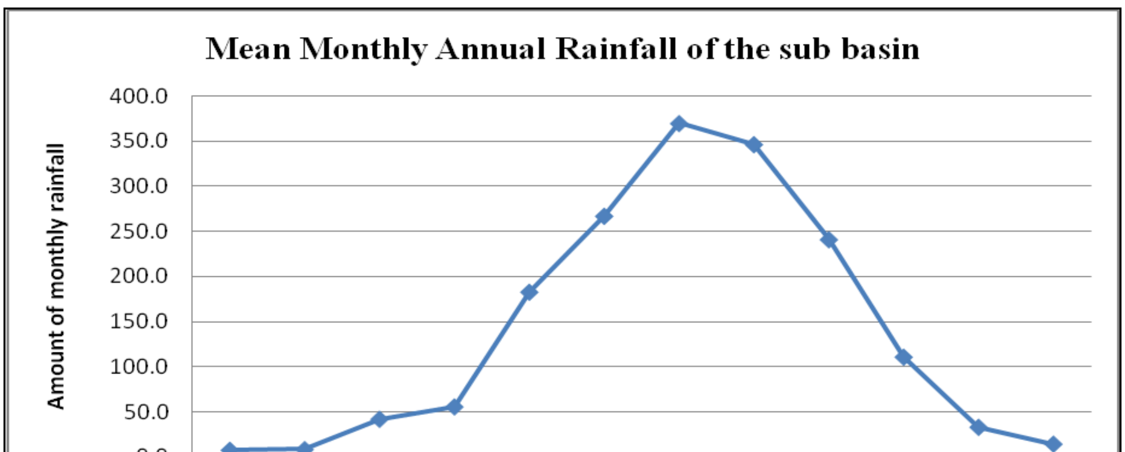
Figure 1-1: Fincha'a Sub Basin and its associated Abbay River Basin

2. Climate: The climate of Ethiopia mainly controlled by the migration of Inter-Tropical Convergence Zone (ITCZ), which conditioned by the convergence of trade winds of the northern and southern hemisphere and the associated atmospheric circulation. It is also highly influenced, regionally and locally, by the complex topography of the country. The Variation of the spatial and temporal precipitation distribution over Ethiopia is significant and the mean annual rainfall pattern points to four distinct rainfall regimes. NMSA (1996) gives four rainfall regimes in Ethiopia: mono-modal, bimodal type I, bimodal type II, and diffused pattern.

Mono-modal – The area dominated by a single maximum rainfall pattern. **Bimodal type I** is area characterized by a quasi-double maximum rainfalls pattern with a small peak in April and maximum peak in August. **Bimodal type II** – The area dominated by double maximum rainfall pattern with peaks during April and October. **Diffused pattern** – The area characterized by irregular rainfall pattern. Though erratic rainfall prevails from August/September to

January/February, the region does not have a well-defined rainfall pattern. The Fincha'a sub basin dominated by bimodal type I rainfall pattern.

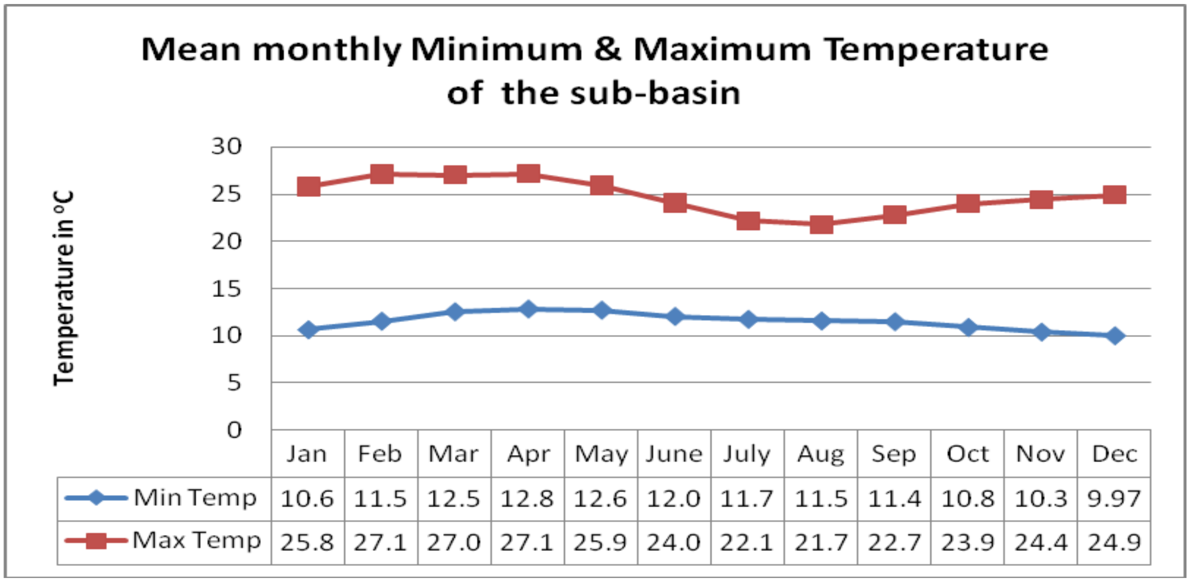
Fincha'a sub-basin also experiences two rainy seasons due to the annual movement of the ITCZ, the first that brings the main rains from June to September and the short rains from February to April. Climate in the sub basin highly influenced by the effects of elevation as other parts of the nation, which gives rise to distinct zones and characteristics (NMSA 1996; MoA 2000). According to the data obtained from Shambu, Fincha'a, Neshe, Homi, Combolcha and Embabo metrological stations (1995 to 2015), the sub basin has an annual rainfall ranging between 1367 mm and 1842 mm. The average annual rainfall of the sub basin is about 1678 mm/year. Lower annual rainfall observed in the northern lowlands of the sub basin and higher rainfall greater than 1500 mm observed in the western and southern highlands of the sub-basin. About 73% of the annual rainfall of the sub basin falls between June and September. The annual maximum and minimum temperature in the sub-basin varies between 21.2˚C – 27.9˚C and 9.9˚C – 14.35˚C, respectively. The average annual maximum and minimum temperature of the sub basin is about 24.8^{O}C and 11.5 ^{O}C respectively.



	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Series1	7.4	8.1	41.8	55.5	183	267	370	347	241	111	32.9	14.1

Figure 1-2: Mean Monthly Annual Rainfall of the Sub–basin

(Source: Constructed from a raw data of National Meteorologica Agency of Ethiopia [NMA])



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Min Temp	10.6	11.5	12.5	12.8	12.6	12.0	11.7	11.5	11.4	10.8	10.3	9.97
Max Temp	25.8	27.1	27.0	27.1	25.9	24.0	22.1	21.7	22.7	23.9	24.4	24.9

Figure 1-3: Mean Monthly Minimum and Maximum Temperature of the Sub–basin
(Source: Constructed from a raw data of NMA)

To visualize the trend of long term (in this case 20 years) climate variables of meteorological data of precipitation and temperature recording of the nearby four weather stations over the period of 1995 to 2015 is presented graphically in Fig 1-4 to Fig 1-7. According to the graph of trend analysis precipitation in Fincha'a and Shambu stations, show a decreasing trend; while in Neshe and Homi stations show an increasing treand. Maximum and minimum temperatures in all of the stations are visibly increasing as time goes on except in maximum temperature of Neshe.

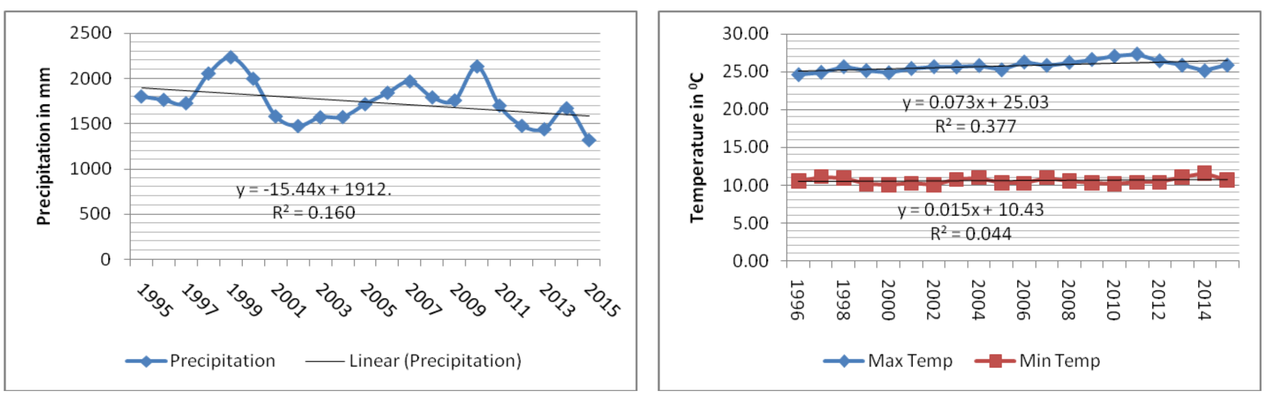


Figure 1-4: Trend of Precipitation and Temperature in Fincha'a
(Source: Constructed from a raw data of NMA)

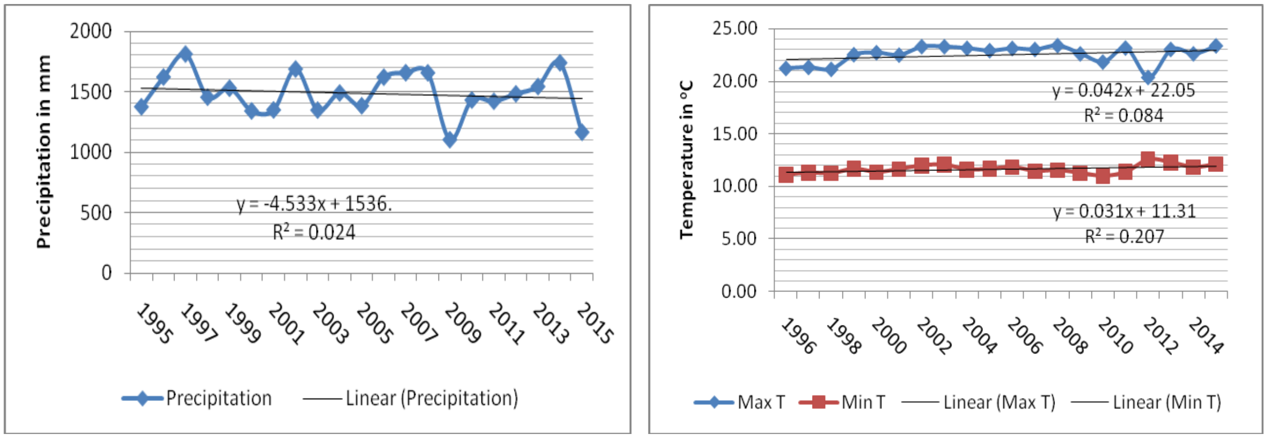


Figure 1-5: Trend of Precipitation and Temperature in Shambu
(Source: Constructed from a raw data of NMA)

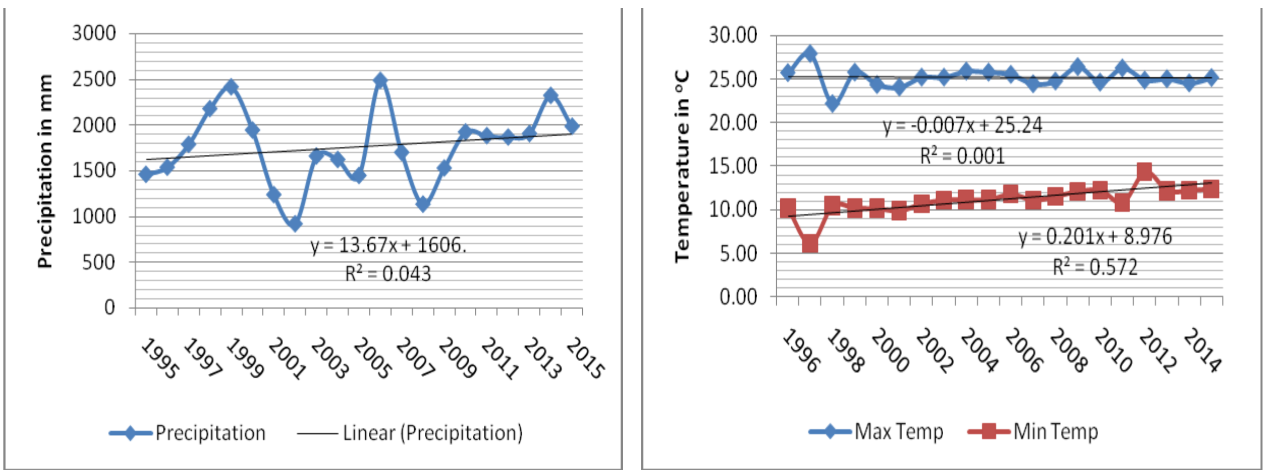


Figure 1-6: Trend of Precipitation and Temperature in Neshe
(Source: Constructed from a raw data of NMA)

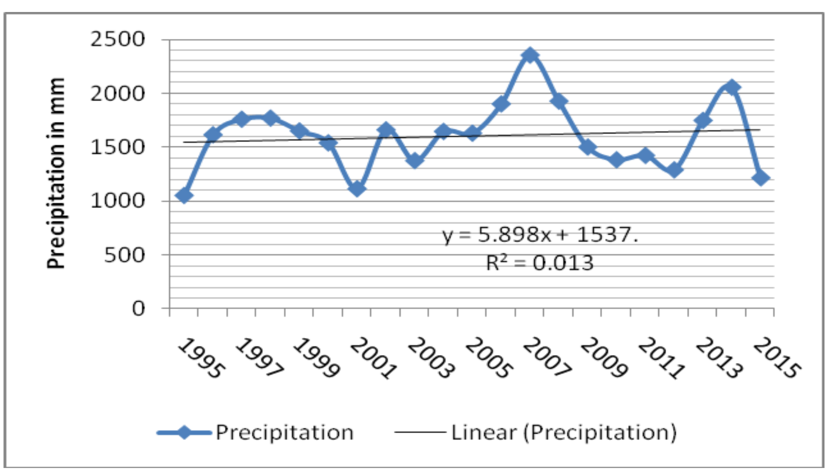


Figure 1-7: Trend of Precipitation in Homi
(Source: Constructed from a raw data of NMA)

The regression analysis reveals that precipitation in Fincha'a and Shambu weather stations is declining, whereas in Neshe and Homi stations somewhat increasing. Time (in year) explains 1.3%, 2.4%, 4.3% and 16% of the variation in precipitation in Homi, Shambu, Neshe and Fincha'a weather stations respectively. As can be seen in Table 1-1, precipitation varies from 4.53 to 15.44 mm per year either positively or negatively. However, the variations are not statistically significant.

Table 1-1: Analysis of precipitation data from 1995 to 2015

Precipitation in mm				
	Fincha'a	Shambu	Neshe	Homi
Minimum	1316.0	1106.1	917.6	1056.50
Maximum	2237.6	1809.3	2483.6	2351.60
Mean	1742.35	1486.46	1756.67	1602.04
Sta. Deviation	239.11	179.05	406.09	313.32
Correlation with time	-0.4	-0.155	0.207	0.114
Trend (per year)	-15.440	-4.533	13.670	5.898

Source: Estimation of a raw data obtained from NMA

Maximum temperature increases in Fincha'a, Shambu, and show a declining trend in Neshe weather stations slightly (Table 1-2). The variations are stastically insignificant in three of the weather stations.

Table 1-2: Analysis of maximum temperature data from 1996 to 2015

Maximum Temperature in ^{0}C			
	Fincha'a	Shambu	Neshe
Minimum	24.65	20.35	22.15
Maximum	27.34	23.36	27.9
Mean	25.81	22.5	25.17
Sta. Deviation	0.71	0.875	1.134
Correlation with time	0.614	0.29	0.032
Trend (per year)	0.073	0.042	-0.007

Source: Estimation of a raw data obtained from NMA

As regard to minimum temperature, change in time explains 4.4 to 57.2 percent of the variation in minimum temperature. The trend goes increasing in all stations but with the exception of Neshe weather station, the other two stations (Fincha'a and Shambu) statistically insignificant.

Table 1-3: Analysis of minimum temperature data from 1996 to 2015

	Minimum Temperature in ^{0}C		
	Fincha'a	Shambu	Neshe
Minimum	10.030	10.990	6.130

Maximum	11.630	12.580	14.350
Mean	10.590	11.650	11.09
Sta. Deviation	0.433	0.414	1.575
Correlation with time	0.210	0.455	0.756***
Trend (per year)	0.015	0.031	0.201***

***, **, and * indicate 1, 5, and 10 percent significance levels respectively.

Source: Estimation of a raw data obtained from NMA

Agro ecologically, the sub basin is characterized by tepid to cool and sub humid mid highlands and moist mid highlands, and the lowlands in the northeastern parts of the basin being hot to warm moist lowlands. Potential Evapotranspiration (PET) in the sub basin is generally between 1365 mm and 1970 mm per year. PET is higher greater than 1800 mm/yr, in the lowlands where high temperature is observed. The highlands in the western and eastern parts of the basin show lower PET, less than 1600 mm/yr (Denekew and Bekele 2009).

3. Topography: Fincha sub basin has an area of 4,089.5 km^2. The altitude in Fincha sub basin ranges approximately between 836 masl and 3209 masl. The highlands in the western and southern part of the sub basin are higher in altitude, greater than 2200 masl up to 3209 masl. The lowlands have lower altitude less than 1800 masl in the northern parts of the sub basin.

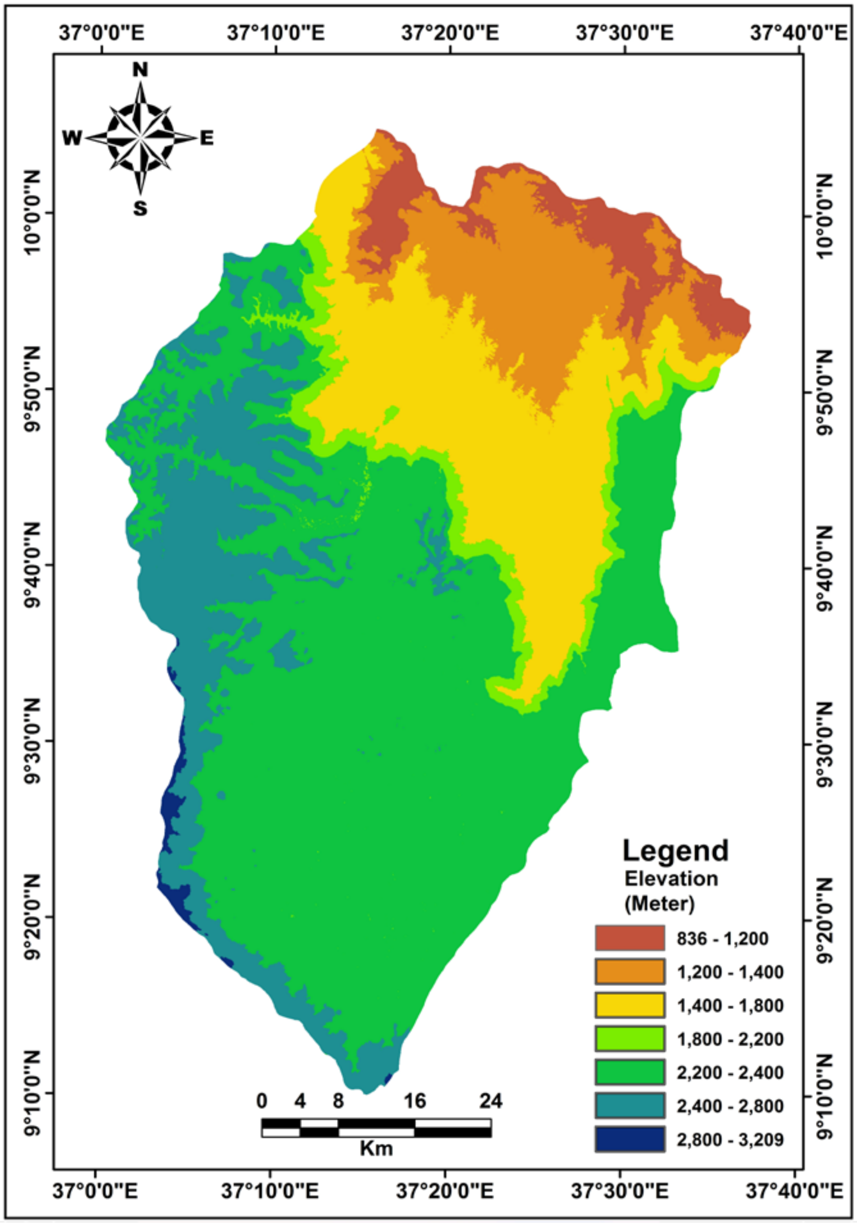


Figure 1-8: Topography of Fincha'a Sub Basin

4. Geology and Soil: Geologically, the sub basin predominantly underlain by Mesozoic sedimentary formations consisting of horizontally bedded sandstones and shales of the Adigrat Formation. Alkaline Olivine Basalts underlie the upper ridge of the sub basin. Below the ridge on the plateau and in the upper gorge are the Adigrat sandstones. The Mesozoic sedimentary units of the Adigrat Formation (upper Triassic to middle Jurassic age) have deposited unconformable on the eroded surface of the Precambrian basement complex. The Adigrat Formation is composed of a transgressive series of alternating sandstone and shale layers. At the contact between the basalt and the Adigrat Formation, there is a layer of volcanic agglomerate. The agglomerate is composed of particles of various size and composition, ranging from ash to cobble, and appears to have incorporated some of the ancient valley fill material (EEPC 2005).

According to FAO (2006) soil classification of Ethiopia, the prevailing soil type in the steep slopes of the sub-basin ridge is underline by Leptosols. It is unattractive soil for rainfed agriculture due to their shallowness and often gravelly with low water holding capacity. They are very prone to erosion.

On the plateau and the flatter areas in the gorge, there are extensive areas of Nitosols within the Sub-basin. Nitosols are rich red to red-brown in color and clay-rich soils. Nitisols have deep (>150 cm) and uniform profile which is suitable for deep crop root growth and has high water holding capacity. The soil structure is loose to friable. They are among the relatively productive soils. However, it is at risk from erosion. With care and management of the organic matter and preferably constant ground cover, they can support permanent cropping (Sanchez 1976).

In other parts of the sub basin: Regosols (very stony), lithosols (shallow and stony), Lixisols, and Petric Gypsisols found on the very steep slopes of the escarpment. On the less steep slopes of the lower gorge, lithic Leptosols found which are even more stony and shallow than their Highland counterparts.

5. Soil Fertility Management: Farmers of the sub basin practice different soil management practice to maintain the productivity of the soil. One of the practice is livestock corralling for soil fertility management and locally known as <<Chichessu>>. Chichessu is the local name given to the traditional soil fertility management practice dominant in the sub-basin in which the corrale (Beret) to enclose the animals in place. This corrale changed every 5 to 10 days to adjacent land unit until the whole field reached. The time and size of the fence (Beret) also depends on the number of animals the household owned.

Figure 1-9: Photo Showing Traditional Soil Fertility Management Practice (Chichessu)
(Source: Own photograph from the field research)

6. Traditional Agro-forestry Practice: Another important practice by farmers of the sub basin revealed during the assessment of the sub basin and the focus group discussion was the agro-forestry practices in the sub basin that had long history especially in the form of scattered trees on the farmland and home garden. Peoples used to plant both indigenous and exotic tree species. The most common practice as long as home garden agro-forestry is concerned is the plantation of *Eucalyptus globulus* and *Eucalyptus camaldulensis* tree species.

Other indigenous tree species planted in home gardens include *Croton macrostyches, Arundianria alpine, Arundo donax, Adathoda shimperina, Eritrina bruci, Ephorbia abysinica, Vernonia amagadelina*. The preference of these species by farmers emanated from their easiness for management and absence of severe negative impact on the neighboring farmland. The other reason is their fast growth habit, the most important criteria set by the farmers. The trend in planting slow growing endemic tree species like *Olea Africana*, and *Juniperous procera* found to minimal level.

Coming back to the scattered trees on farmlands, it is the most widely used and most acceptable practice among the agro-forestry practices. In the Fincha'a Sub-basin, one can observe quite diversified tree species and management interventions as far as scatter tree on farmland are concerned. The most common tree species in the sub basin are *Croton macrostacheys, Comberatum molle, Ficus vasta, Ficus sure, Acacia abyssinica, Acacia albida, Eucalyptus camaldulensis, Ertirina bruci, Cordia Africana* and many others, which need critical investigation.

The most common management practices undertaken in the sub basin are the practice of lopping and pollarding. Through lopping and pollarding, the communities collect quite huge biomass for their livestock and for their domestic fuel wood consumption. Equally importantly, farm implements and fencing materials found commonly from this sources. Currently, farmers focus only to manage the already existing trees on their farmland. The practice of neither planting new tree species nor recruiting seedlings from natural regeneration is significantly low. The main reasons according to the farmers were free grazing coupled with land shortage.

Finally, even though the indigenous practices are so great, one important observation in the sub basin is that only there is little success in the modern agro-forestry technologies like alley cropping and others. Therefore, in the plan to expand agro-forestry and forestry activities emphasis has to given to the indigenous practices and by taking this lesson, it is possible to introduce and scale up the modern agro-forestry technologies.

7. Land Use/Land Cover: The most widespread land cover is rain fed cultivation covering 57 percent of the Sub-basin. Wetland, open woodland and grassland make up 15, 12 and 10 percent of the area respectively. The remaining 6 percent of the area covered with water with a very small area of forest (MoWIE 2014). The water cover is the result of the three hydroelectric dams constructed by the government for power generation: Fincha hydroelectric dam constructed in 1975, Amerti dam constructed in 1987 to increase the capacity of Fincha hydroelectric power generation by diverting the water through tunnel, and the Neshe hydroelectric dam constructed in 2011.

8. Vegetation Typical for the area: Phytogeographically, the ecoregion mapped as Afromontane vegetation and considered part of the Afromontane archipelago-like regional center of endemism (White 1983). In the lowland AES (Warm Semiarid) below 1800 m.a.s.l., the main vegetation type is dry woodlands savannah, with bush land on the steeper slopes and riverine vegetation near the watercourses.

The identification of trees and shrubs species found in the sub basin conducted during field survey. Species level identification made using expert knowledge and by means of local names provided by people in the area. The local names then checked against the lists presented in various publications, particularly Flora of Ethiopia, Volume 3. Even though, it is not exhaustive, some of the trees and shrubs found in the sub basin include the following. *Acacia abissinica, Acacia nilotica, Albizia gumifera, Pouteria adolfi-friedericii, Carissa edulis, Celtis africana, Combretum spp., Cordia africana, Croton macrostachyus, Dodonaea angustifolia, Ekebria cafensis, Eucalyptus globulus, Eucalyptus camaldulensis, Ficus sycomorus, Ficus vasta, Hygenia abissinica, Juniperus procera, Maytenus arbutifolia, Nyrica salicifolia, Olinia rochetiana, Olea africana, Osyris lanceolata, Phoenix reclinata, Podocarpus falcatus, Prunus africanus, Rosa abyssinica, Salix subserrata, Syzygium guineense and Vernonia amaygdalina.*

1.5.2 Socioeconomic Setting

Administratively, the Fincha'a sub basin is located in Oromia regional state, Horo Guduru Wollega Zone of Horo, Guduru, Hababo Guduru, Abbay Chomen, Jima Geneti, Jima Rare, and Jardega Jarte Districts. According to CSA (2013) population projection of Ethiopia from 2014 to 2017, the total population of the sub basin assumed 577,467 (Table 1-1), and the average density of the population is about 153 people per km^2. Densities are highest on the plateau and ridges of the sub basin.

Table 1-4: Population size and area coverage of Fincha Sub basins at Woreda level.

Zone	Woreda	Area (KM^2)	Population (July, 2016)		
			Male	Female	Total
Horo Gudru Wellega	Horo + Shambu town	603	58,633	58,859	117,492
	Guduru	716	61,581	62,419	124,000
	Hababo Guduru	688	28,582	28,528	57,110
	Abbay Chomen	895	32,365	30,543	62,908
	Jima Geneti	397	40,391	41,520	81,911
	Jima Rare	117	35,202	36,525	71,727
	Jardega Jarte	657	31,049	31,270	62,319
	Others	16.5			
	Total	4089.5	287,803	289,664	577,467

Agriculture is the main economic stay of the people of the sub basin. The diversified Agro-ecological systems with distinct climatic, soil and altitude differences give an opportunity for growing a varied range of crops like cereals, oilseeds, pulses, and vegetables. Agriculture in the sub basin is predominantly mixed crop-livestock systems, practiced by subsistence farmers on small plots. The major crops grown are tef (*Eragrostis abyssinica*), wheat (*Triticum aestivum*), barley (*Hordeum vulgare),* sorghum (*Sorghum bicolor*), maize (*Zea mays*), and oats (*Avena spp.*) are among cereals. Faba beans (*Vicia faba*), field peas (*Pisum sativum*), mung beans (*Vigna* *mungo*) and haricot bean (*Phaseolus vulgaris*) are among food legumes. Noug (*Guizotia abyssinica*), linseed (*Linum usitatissimum*), rapeseed (*Brassica napus*), and sesame (*Sesamum indicum*) are among oil crops. Potato (*Solanum tuberosum*), onion (*Allium cepa*), and garlic (*Allium sativum*) are among horticultural crops grown in the sub basin. Cereals, food legumes, and oil crops are crops grown in descending order of area coverage.

The farming system in the sub basin is dominated by cereal production system that accounts for about 75% of the total cultivated area. From cereals: tef, wheat, and maize account 30.9%, 23.6%, and 19.9% respectively. Most cereal crops particularly tef and wheat are planted on fine seedbed and provided little groundcover during the most erosive storms in July and early August. This is combined with steeply sloping upland area and poor land management practices contribute to the land degradation currently observed in the area.

In the sub basin, the cropping system is also dominantly mono cropping of the first three major kinds of cereal, i.e., tef, wheat, and maize. Intercropping and double cropping practiced in the sub basin to a limited extent. Crop rotation is practiced almost by the entire farmers of the sub-basin. In the area, farmers follow rotations like cereal-pulse-cereal or oil crop-cereal-pulse or cereal-cereal-oil crop or root crops-cereals-pulse or cereal-cereal-pulse.

Of the major crops grown in the sub-basin, mainly Niger seed, sesame, mung bean, and tef are cash crops and the others used for home consumption while also sold. Oxen used as traction power for land preparation. Land preparation, weeding, and harvesting are the most laborious agricultural activities and they are activities that wealthier households will pay for. Ball worm, termites, and stock borer are the main pests that affect crop production. Ball worm affects Niger seed, termites affect all types of crops and stock borer affects maize. Niger seed ball worm is a pest unique to the sub-basin. Agriculture is predominately rain-fed. An insignificant amount of land is currently under irrigated agriculture whereby traditional irrigation schemes have the dominant share.

1.6 Conceptual Framework

A conceptual framework could be a simple list of concepts and their likely associations or a more illustrative schematic diagram of important factors, expected relationships, and possible outcomes of the research problem. It enables the researcher to critically consider multiple facets of the research problem, identify key factors, and depict their logical interrelationships in a scheme. Thus, a thoughtfully developed conceptual framework can serve as a vital compass to assist focusing a study towards the central research problem. It also shows how the researcher conceptualizes the current problem and clarifies goals and expectations of a research (Ulin et al. 2005).

Considering the above idea and reviewing different theoretical and empirical literatures of vulnerability and adaptation strategies to climate variability and change, the conceptual frameworks that guide this particular study was developed within the setting of agroecosystems. The diagrammatic form of the conceptual framework that displays interrelationships among key factors and their likely outcomes depicted in Figures 1-10 below.

A comprehensive understanding of the sub basin requires the analysis of agroecosystems, the relative vulnerability of agroecosystems to climate variability and change, the corresponding adaptation strategy employed by smallholder farmers and examining the status of soil erosion, which is an indication of the resilience of the system.

The motive of understanding agroecosystem based impact and adaptation strategy to climate variability and change by smallholder farmers emanated from the constructs of agroecosystem vulnerability to climate variability and change. It is because of the existence of agroecosystem vulnerabilities at smallholder level that we are determinedly care to understand impacts and adaptation. If the livelihood of the society had not been vulnerable, we should not have paid due attention to the impact and adaptation to climate variability and change at all. That is why the terms agroecosystem, vulnerability and adaptation concepts have gained attention in this particular research.

Vulnerability is context specific so that there cannot be a single and unifying definition and approach (Pearson & Langridge 2008). In simplest term, vulnerability used to describe the condition of susceptibility to be harmed. It often conceptualized as a function of the character and magnitude of stressors to which a system is exposed, its sensitivity, and its capacity to deal with the effects of these stressors (IPCC 2001). This definition suggests that vulnerability relates to the sources of stressors, which are external to a system, and to a system itself that must seek to cope with them. The relevant system may be human, such as an individual or a population; a business enterprise or an entire economy; or an ecological system including a single species or an entire ecosystem.

Based on this IPCC definition, the relationship among the primary determinants of vulnerability illustrates in Figure 1-10. The main elements in the conceptual framework include the following.

Climate variability and change: The entry point for the conceptual framework of this study is climate variability and change such as increased temperature, amount and variable rainfall, and extreme weather events. These factors cause vulnerability in two ways: externally and internally. The external side includes risks, shocks, and stress to which an individual or household are subjected, whereas internal side mainly constitute lack of means to cope without damaging loss (Chambers and Conway 1992). The temporal properties such as frequency, magnitude, duration, and suddenness of extreme climatic events, which constitutes external side of vulnerabilities, significantly influence adaptive capacity of individual or household. The aforementioned temporal properties determine the extent of damage inflicted. For example, extended extreme events are likely to inflict greater damage compared to the shorter ones. Whereas compared to extreme events that take long time to form, sudden events with the high speed of onset causes more damage. It does not provide any opportunities for preventative forms of adaptation (Smithers and Smit 1997).

The manifestations of climate change are slowly emerging in the increase in both the magnitude and frequency of extreme hazards, including flood and drought. Long-term changes in climate trends, such as changes in rainfall and temperature, are thereby causing rapid and slow onset of disturbances in natural resources and ecosystem services on which poor communities depend for their subsistence and income. This has to aggravate the inherent vulnerability in low-income countries plagued by structural problems of poverty, underdevelopment, food and livelihood insecurity, socio-political inequalities, and power differentials. Given this realization of the daunting challenges of climate change, adaptation to the impacts of climate change is now at the forefront of scientific research and policy negotiations (Tschakert and Dietrich 2010). Therefore, understanding the impact of climate variability and change are crucial to the understanding of smallholder farmers, and their ability to adapt and remain resilience after accumulated impacts from external factors.

Livelihood Capitals: A livelihood comprises the capabilities, assets and activities required for a means of living. Every agro-ecosystem and the households residing within the respective agroecosystems require important resources. These include human, physical, natural, financial and social capitals. These capital assets play a crucial role in determining both the vulnerability and adaptation. The institutions and policies have a profound influence on access to assets. Those with more assets tend to have a greater range of options and an ability to switch between multiple strategies to secure their livelihoods.

Vulnerability of Agroecosystems and Households: Within a certain endowments and entitlements, and institutions and processes in a given agro-ecosystem and the households living in the agro-ecosystem will expose to various aspects of climate variability and change; and the level of vulnerability measures by their adaptive capacity, sensitivity and exposure.

Adaptation: a given agro-ecosystem and the households living in this agro-ecosystem with certain endowments and entitlements, and institutions and processes exposed to climate variability and change will strive to minimize and/or avoid vulnerability by employing various adaptation strategies and practices to be climate resilient. This in turn has an effect on endowments and entitlements, and institutions and processes.

Adaptation is a process of making and implementing decisions by an individual, organization, or government with regard to managing risks related to changes in climate, using the adaptive capacity available to those actors (Nelson 2011). The factors related to general adaptive capacities include economic wealth, social networks, and equity, whereas in the operation context, the related factors include knowledge and skills, access to resources and technology, and institutional supports (Wesche and Armitage 2010).

Scholars argue that developing economies, with limited access to information and technology, poor infrastructure, low level of skills, weak institutions, and inequalities in power and access to resources, have little capacity to adapt and are thus vulnerable to climate change (Grothmann and

Patt 2005). However, based on empirical research, numerous authors note that adaptive capacity alone does not automatically trigger adaptation (Naess et al. 2005).

The common adaptation strategy to climate variability and change by smallholder farmers' guided by action theory and sustainable livelihood framework. The action theory of adaptation developed by Eisenack and Stecker (2011) viewed that adaptation process to climate change is the interface between environmental stimuli with three core adaptation functions of the actor namely exposure unit, receptors and operators. The changes in meteorological variables such as rainfall and temperature on a given social system affect the exposure unit (human & non-human systems) and hence trigger the onset of adaptation process.

The operator groups comprises individual or collective of actors who exercise the response towards adaptation to the impact of climate variability and change. As pointed out in the theory, action from the actors must be with the purpose of adapting to climate variability and change. The theory describes receptors as the actor that is the target of an adaptation. However, Eisenack and Stecker (2011) pointed out that implementation of adaptation by an operator needs resources such as access to financial, technology, legal power, social networks, knowledge or availability of information.

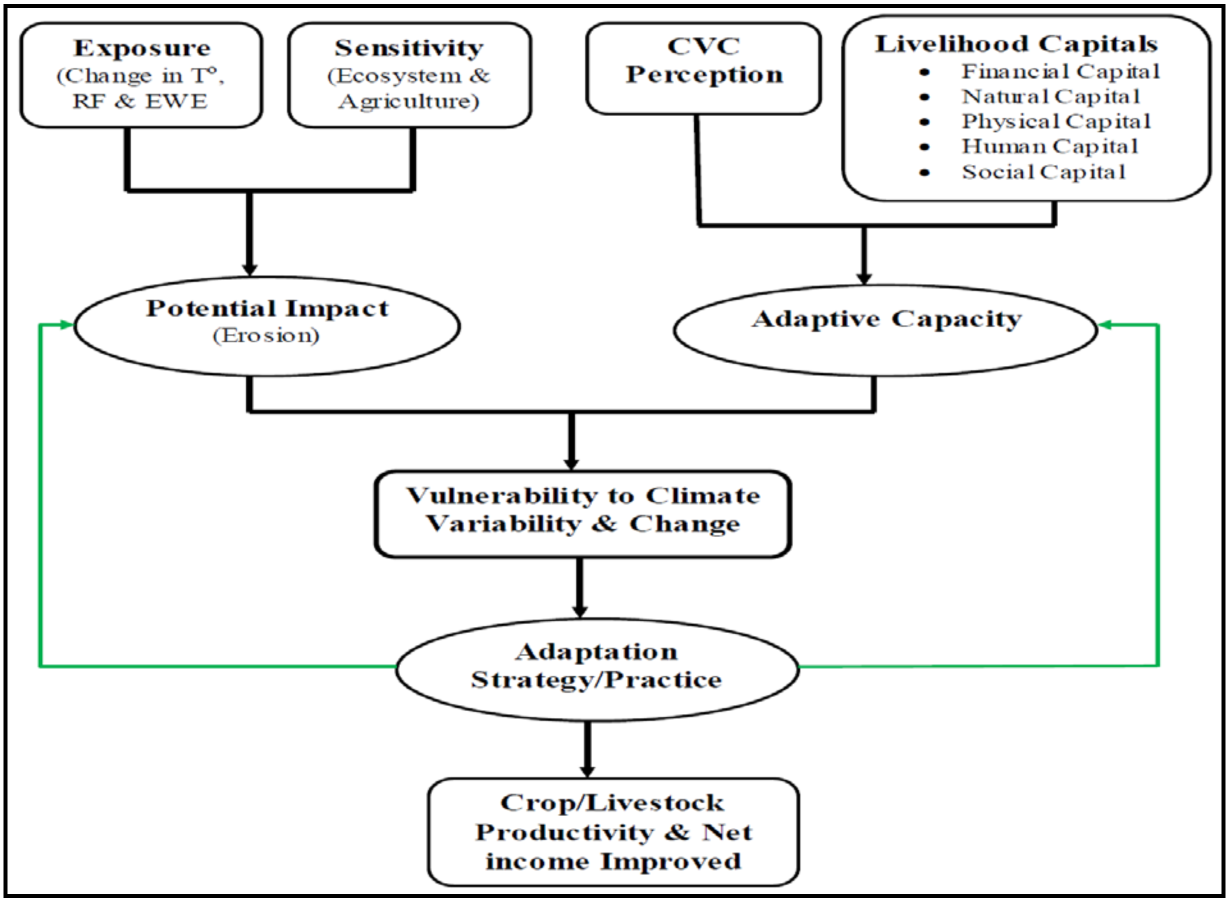


Figure 1-10: Conceptualization of Vulnerability, Adaptation, and Erosion Hazards according to the LVI-IPCC Framework

Likewise, sustainable livelihood framework proposed by Corney (1998) shows that institutions, organizations, policies and legislation shape people's livelihood strategies. The framework puts people's livelihoods and their interactions with their environment at the centre. He argues that, the institutions and organizations through types of policies and legislation that shape livelihood strategies of people influence community and household assets such as financial capital, social capital, physical capital and natural capital.

Corney's approach observed that ability to pursue different livelihood strategies is dependent on how human capital such as skills, knowledge and good health, and social capital such as membership to more formal social groups. Moreover, 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 livelihood strategies to mollify vulnerability caused by climate variability and change impacts.

Hazard: hazard is a potentially damaging influence on the system of analysis. United Nations/ISDR (2004) defines 'hazard' broadly as "a potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation". Hence, a hazard understood as some influence that may adversely affect a valued attribute of a system. In this particular study, erosion considered as a hazard because it causes soil loses thereby reduced fertility of the soil and silitation of the dams. If the fertility of the soil decreases, the amount of production also proportionally reduced and thereby increased the level of vulnerability.

The magnitude and severity of extreme weather events also affects the amount of soil loss by erosion. In turn, erosion also increases the sensitivity of the system or causes damage to the natural capital of the agroecosystems and the households residing with the respective agroecosystems. In the same way, soil-loss (erosion hazard) affects the production and productivity of agro-ecosystem and by doing that, it affects the adaptive capacity of the community. Hazards often distinguished into discrete hazards, denoted as perturbations, and continuous hazards, denoted as stress or stressor (Turner II et al. 2003).

1.7General Methodological Approach

1.7.1 Philosophical Foundation

Philosophical ideas influence the practice of research and require identification. Because the information will help to explain why we chose qualitative, quantitative, or mixed methods approaches for our research (Creswell 2014). Here worldview meaning "a basic set of beliefs that guide action" (Guba 1990). According to Creswell (2014), worldviews are seeing as a general philosophical orientation about the world and the nature of research that a researcher brings to a study.

Generally, there are about four philosophical worldviews or beliefs researchers bring to inquiry that one may choose to employ in conducting a research work. It includes the post-positivist, constructivism, transformative, and the pragmatic worldviews (Creswell 2014). Either of these worldviews used based on discipline orientations, students' advisors/mentors inclinations, and past research experiences. The types of beliefs held by individual researchers based on these factors will often lead to embracing a qualitative, quantitative, or mixed methods approach in their research. Consequently, among the four worldviews, the pragmatic worldview pursued for this particular study.

Pragmatism derives from the work of Peirce, James, Mead, and Dewey (Cherryholmes 1992). Other writers include Murphy (1990), Patton (1990), and Rorty (1990). There are many forms of this philosophy, but for many, pragmatism as a worldview arises out of actions, situations, and consequences rather than antecedent conditions as in post-positivism (Creswell 2014). There is a concern with applications—what works—and solutions to problems (Patton 1990). Instead of focusing on methods, researchers emphasize the research problem and use all approaches available to understand the problem (Rossman & Wilson 1985). As a philosophical underpinning for mixed method, studies Morgan (2007), Patton (1990), and Tashakkori and Teddlie (2010) convey its importance for focusing attention on the research problem in social science research and then using pluralistic approaches to derive knowledge about the problem. For the mixed methods researcher, pragmatism opens the door to multiple methods, different worldviews, and different assumptions, as well as different forms of data collection and analysis (Creswell 2014).

1.7.2 Research Approach

According to Creswell (2014), there are three advanced research approaches: Qualitative, Quantitative and Mixed methods. The three approaches are not as discrete as they first appear. Qualitative and quantitative approaches should not view as rigid, distinct categories, polar opposites, or dichotomies. Instead, they represent different ends on a continuum (Newman & Benz 1998). A study tends to be more qualitative than quantitative or vice versa. Mixed methods research resides in the middle of this continuum because it incorporates elements of both qualitative and quantitative approaches. The broad research approach is the plan or proposal to conduct research, which involves the intersection of philosophy, research designs, and specific methods (Creswell 2014).

For this particular study a mixed methods research is the preferred approach employed. The benefit obtained from mixed method approach to investigate the research problem dictated the choice of this approach. Mixed methods approach involves combining or integration of qualitative and quantitative research and data in a research study. Qualitative data tends to be open-ended without predetermined responses while quantitative data usually includes closedended responses such as found on questionnaires or psychological instruments. The field of mixed methods research is relatively new with major work in developing it stemming from the middle to late 1980s (Creswell 2014).

1.7.3 Research Design

Research designs are types of inquiry within quantitative, qualitative, and mixed methods approaches that provide specific direction for procedures in a research design (Creswell 2014). Others have called them strategies of inquiry (Denzin & Lincoln 2011). Although many designs exist in the mixed methods field, Creswell (2014) identified the three primary models found in the social sciences today: convergent parallel mixed methods, explanatory sequential mixed methods, and exploratory sequential mixed methods.

To comprehend the interrelated objectives of the study mixed methods designs (Convergent parallel mixed methods), which combines both quantitative and qualitative methods across the stages of the research, was entailed. **Convergent parallel mixed methods** are a form of mixed methods design in which the researcher converges or merges quantitative and qualitative data in order to provide a comprehensive analysis of the research problem. In this design, the investigator typically collects both forms of data at roughly the same time and then integrates the information in the interpretation of the overall results. Contradictions or incongruent findings explained or further probed in this design.

Even though it was mixed method approach, the quantitative research methodology formed the basis of this study. The two approaches are complementary, providing different perspectives and answering different specific questions within any one broad area (RDSU 2003). Mixed method design enhances the integrity of the research findings and helps to augment findings from different angles, and creates a comprehensive account of the research area (Bryman 1988; Creswell 2014). It is based on the assumption of collecting diverse types of data best provides a more complete understanding of a research problem than either quantitative or qualitative data alone. The study integrates both the quantitative (survey method) and open-ended interviews to collect detailed views from participants to help explain the quantitative survey in order to generalize results to a population. Both forms of data collected roughly at the same time and then integrate the information in the interpretation of the overall results.

Of the different research designs, survey research is one of the non-experimental quantitative research design methods. It includes cross-sectional and longitudinal studies using questionnaires or structured interviews for data collection (Creswell 2014). Cross-sectional research design has three distinctive features: no time dimensions; reliance on existing differences rather than change following intervention; and groups based on existing differences rather than random allocation (De Vaus 2001). Hence, this research design is preferred for this study.

Climate variability and change vulnerability and adaptation strategies of agroecosystems found in Fincha'a Sub-basin studied in this research. Since the studies employed convergent parallel mixed methods design, both quantitative and qualitative methods engaged. Further to reviewing relevant literatures and observations, household survey conducted from May to June 2017 after pre-testing the questionnaire on April 2017. Similarly, to augment the quantitative information obtained from household survey, focus group discussions [FGD] and key informant interviews [KII] with individual farmers undertaken from May to June 2017 by using semi-structured checklists to generate additional in-depth qualitative information. The number of FGD and KII was decided based on time and financial constraint.

1.7.4 Sampling Design

Different sampling design technique employed for qualitative and quantitative data sets. For the qualitative data set, a non-probability sampling approach used in order to identify the sample units (participants) for the study. These include intensity sampling, stratified purposive sampling, and criterion based sampling.

Whereas for the quantitative data set, the sample survey utilized a multi-stage sample design technique to select the Kebeles and households moving from the most general level (areas having similar agro-ecosystem) to the most precise level (household). In the first stage, the sampling procedure involved selection of the study sub-basin. The study sub basin *(*Fincha'a) purposefully selected because the sub-basin is less researched interms of climate variability and change, and expressed as one of the erosion hot spot and vulnerable areas of the Blue Nile river basin of Ethiopia (MoWIE 2014).

In the second stage, the Districts found in the sub-basin grouped into the possible agroecosystem in consultation with Zonal and Woreda agricultural offices. Then, representative Districts that represent the four climate zones selected randomly. The significance was to enable the research to focus on similarity and differences in vulnerability and adaptation strategy, depending on local context and circumstances, to climate variability and change on specific agroecosystem.

The third stage involved selection of kebele administrations within the selected woredas. The number of kebeles was decided based on time and financial constraint. Finally, a total of 380 mixed crop-livestock farming households selected by systematic random sampling and participated in the cross-sectional survey. The sampling frame (list of households residing in the Kebele) used for selection of households obtained from respective Kebele administration offices.

Sample size determination for the study made following Kothari (2004) references of the study population. The approach to determine sample size is valid only if simple random or systematic random sampling methods are applied. According to Kothari (2004), the total sample size of households interviewed from finite population was determined based on the following equation:

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

Where, n = Sample size

N= total households which is 40, 803 (Total sum of household size from the sample Woredas)

p[1] = sample proportion, q = 1 – p; which is equal to 0.5

e = the maximum acceptable error margin, 0.05 in this case (at 95% level of confidence)

z = 1.96 at 95% (the value of the standard variate as per the table of area under normal curve for the given confidence level for this case of 99%),

Therefore, the sample size is determined to be:

$$n = \frac{1.96^2.(0.5)(0.5).(40803)}{0.05^2(40803-1) + 1.96^2.(0.5).(0.5)} = \frac{39187.2}{102.965} = 380$$

Conserning the selection of watershed for soil erosion hazard assessment; although, thereare many watershed in the sub basin, the Neshe dam watershed selected for erosion hazard

[1] *To estimate p, one method may be to take the value of p = 0.5 in which case 'n' will be the maximum and the sample will yield at least the desired precision. The other method may be to take an initial estimate of p, which either may be based on personal experience judgment or may be the result of a pilot study.*

assessment because of the economic importance of the dam in hydroelectric power generation for the nation and no similar study have been done on the watershed.

1.7.5 Methods of Data Collecion

Generally, this particular research utilized the mixed method approach that encompasses the pragmatic worldview, convergent parallel mixed methods design and collection of both quantitative and qualitative data roughly at the same time in the design. This type of design is popular in fields with a strong quantitative orientation that augments the result with qualitative research methods (Creswell 2014). The quantitative data generated from household survey and secondary sources (like National Meteorological Agency and satellite image). For household survey, instruments like structured questionnaire and semi-structured questionnaire employed. The qualitative data largely depends on information obtained through focus group discussion, key informant interview, and observation. Hence, both primary and secondary data were gathered.

Household survey: A survey has a logical, deterministic, general, parsimonious, and specific characteristic (Babbie 1998). Pertinent to this, households in different agroecosystems of the sub-basin surveyed to generalize them in terms of their level of exposure, vulnerability, perception, and adaptation responses of smallholders to climate variability and change. The survey used to collect a range of data including farmers' perceptions of climate variability and change, adaptation strategy made by farmers, and determinants of adaptation options. The survey questions designed to address the eight profiles used in calculating the livelihood vulnerability index (LVI) and adaptation measures. They included inquiries on socio-economic and environmental attributes as well as their observations regarding patterns of temperature and rainfall over the past 30 years. Household surveys paired with biophysical survey to assess indicators related to land suitability and irrigation potential. During the survey, verbal consent obtained from each head of household. Identifying information recorded was limited to the name of the village and the questionnaire number.

Focus Group Discussions (FGDs): it is a qualitative research method. FGDs were semi-structured discussions held with a small group of persons sharing a common feature. Specifically, old men and women incorporated into the group discussions in order to capture information related to historical trends of climate variability and change, and its overall impact. A shortlist of open-ended questions employed to focus the discussion (Barton et al. 1997). In each of the agroecosystems, two focus group discussions held.

Key informant interviews (KIIs): KIIs are effective methods of collecting information when investigators are interested in understanding the perceptions of participants to phenomena or events (Berg 2009). It used to generate in-depth information pertinent to climate trends over time, land use land cover changes, coping strategies, adaptation measures taken, change in land productivity trends, and crop yield variability. In addition to farmers and development agents working in respective Kebeles, KIIs conducted with representatives of different Zonal and District sectoral offices of the study area. Interview guide used as an instrument.

Observation: Direct observation of the study sites also conducted to look at the environmental setting, physical and biological conservation measures, socio-economic and institutional contexts of the different agroecosystems. Such method of data collection employed in this study as it approaches reality in its natural setting, and offers first-hand information without relying on the reports of others. Moreover, it can offer data when respondents are unable and/or unwilling to cooperate or to offer information (Robson 1993; Kothari 2004; Sarantakos 2005). Checklists used as an instrument. Different types of information such as the biophysical characteristics of the study areas, ground truth data collected from the field, the adaptation strategies and practices used in response to climate variability and change observed and collected at their natural setting.

Secondary data: This includes information on the agroecosystems of the study area, rainfall data, temperature data, crop production data, population data, satellite image, ASTER DEM image, FAO soil maps and other relevant issues related to the study objectives. Generally, data on biophysical environmental, socio-economic and institutional contexts of the study areas collected from secondary sources. Furthermore, research conducted in the area, government strategy and policy documents, and non-governmental organizations and government reports reviewed.

1.7.6 Data Analysis Techniques

The study employed both quantitative and qualitative data analysis techniques. The quantitative data were analyzed using descriptive and inferential statistical tools, whereas, the qualitative data analyzed thematically and the information from the data used to triangulate and substantiate the quantitative data. The qualitative data set also used to capture commonality and divergence across the agro-ecosystem in terms of the variables of interest. The descriptive statistic methods used to disclose the social, economic and demographic characteristics of study households. Furthermore, descriptive tools are applied to compare the agroecosystems of the study sub-basin in terms of the variables of interest that include: households vulnerability, perceptions of climate variability and long-term changes, the impacts of the change, adaptation measures taken to respond to the change and barriers to the implementation of the response. For detailed analysis, the survey data edited, coded and entered into a computer, and then analyzed using SPSS software.

The Livelihood Venerability Index (LVI) framed within the United Nations Intergovernmental Panel for Climate Change (IPCC) is customized based on (Hahn et al. 2009; Mohan & Sinha 2010; Simane et al. 2014; Aryal et al. 2014; Panthi et al. 2015), and contextualized for the agroecosystems specific vulnerability analysis in this study.

The expected soil loss potential (erosion hazard) expressed as tone per hectare per year for the study watershed determined using the Revised Universal Soil Loss Equation (RUSLE) model in a GIS environment. The model estimates rates of rill and inter-rill (sometimes referred to as sheet erosion) caused by rainfall and its associated overland flows. To calculate the annual soil loss from the Neshe Dam watershed, each factor of the soil erosion model namely: climate, soils, vegetation cover, topography and management combined in the empirical Revised Universal Soil Loss Equation (Renard et al. 1997).

Generally, it should be noted that the detailed analytical techniques employed for each of the study objectives provided in the respective papers in the following chapters. The analyzed quantitative data presented in tables, figures, and graphs based on the nature of data generated, and the qualitative data generated presented using narratives.

1.8Scope and Limitations of the study

This particular study conducted in Fincha’a sub basin of the Blue Nile River Basin of Ethiopia. Considering the resource and time available the study delimits the study on agro-ecosystem analysis, climate variability and change vulnerability, and climate change perception and adaptation strategy employed by smallholder farmers in the four agroecosystems of the sub basin.

Moreover, among the different parameters of climate variability and change only issues pertinent to change in temperature, precipitation, and frequency in occurrence of extreme weather events (drought and flooding) examined. Here, an attempt made to see their effects on production, livelihoods, and consequently on the food insecurity situation together with the perception of households and the adaptation strategies pursued so far. With respect to vulnerability, all the three components (exposure, sensitivity and adaptive capacity) treated taking into account the integrated vulnerability assessment approach.

The study also has its own limitations. The first is associated with the design of the study. The study is a cross-sectional survey limited to one time survey in which data collected once from sampled respondents. As a result, overtime trends of important variables and their dynamic linkage not addressed. The other is, in the course of this study, there was the challenge of segregating climate changes from non-climate factors as it were embedded within other settings. However, at most effort made to maintain the quality of the data.

Despite these limitations, the study makes substantial addition to the existing knowledge pool on agroecosystem analysis, climate change vulnerability, climate change perception and adaptation decision, model based erosion hazard assessment for land management practices, and the overall impact of these on the livelihood of the community.

1.9Organization of the Study

The whole dissertation is composed of six chapters. The first Chapter contains the general introduction of the study. Within this chapter, an attempt made to give general background information about climate variability and change from the global to the study sub-basin levels; a brief description of the problem under study together with the justification; the methodology pursued; a description of the study area; and significance of the study conducted.

The remaining sections of the dissertation organized as follows. The second chapter addresses the agro-ecosystem analysis of the sub-basin. This will cover data and information related to the possible agroecosystems found within the sub-basin, crops, livestock, socio-economics, and natural resources of each agro-ecosystem. The analysis revealed that the sub-basin divided into highland, midland, wetland and lowland agroecosystems. The pattern, productivity, and sustainability of the agroecosystems found in the sub-basin discussed in detail. Pattern analysis deals with the identification of Constraints and Opportunities for the management of the system.

The third chapter deals with the agro-ecological system based vulnerability analysis of smallholder farmers' to climate variability and change of the sub-basin. The issues covered under this chapter include climate variability and change vulnerability of agroecosystems. The exposure, sensitivity and adaptive capacity of smallholder farmers in each of the agroecosystem measured and compared. The fourth chapter analyzed smallholder farmers' perception and adaptation to climate variability and change in the sub-basin. Here, the perception, practical experiences of the impact of the climate variability and change; the adaptation strategies pursued by respondents, and the barriers to adaptations are discussed. The fifth chapter examined the expected soil loss potential (erosion hazard) of Neshe hydropower dam by utilizing remote sensing data in the GIS environment.

Finally, the sixth and final chapter puts all these pieces together and makes a synthesis and their policy implications. This chapter describes some of the important lessons learned from the study, and suggests some important actions to be taken by different stakeholders so that the burdens of climate change could be lessened and livelihoods of the households' concerned improved for the better.

2. AGROECOSYSTEM ANALYSIS OF FINCHA'A SUB BASIN

ABSTRACT

Agroecosystems are ecological systems modified by human beings to produce food, fiber or other agricultural products. It is an intersection of a set of agriculturally relevant climatic factors; soils and physiographic variables relevant to crop production; and a prevailing set of cropping practices. The biophysical diversity and associated socioeconomic condition of the community necessitate multiple strategies for augmented the resilience and adaptation to climate change. The objective here is to support site-specific and climate resilient development activities in a changing environment. Hence, the pattern, productivity, and sustainability analysis of the agroecosystems found within the sub-basin analyzed. Primarily, agro-ecosystem analysis conducted in collaboration with experts, development agents, and local communities; and four distinct agroecosystems (Highland, Midland, Wetland, and Lowland) identified. Then, the identified agroecosystems examined in light of their potential for agricultural production and the challenge presented by climate variability and change. The diverse agro-ecosystem offers the potential for the production of equally varied diversified agricultural products with a notable demarcation in terms of production orientation and socioeconomic uniqueness of the community among the agroecosystems. This feature provides an opportunity in addressing the adaptive capacity and resilient development options to climate variability and change based on specific requirement of each agroecosystem.

Keywords: Agroecosystem; Adaptation strategy; Pattern analysis; Fincha sub-basin; Ethiopia

2.1Introduction

Agroecosystems are ecological systems modified by human beings to produce food, fiber or other agricultural products (Conway 1987). Agroecosystems are fundamentally different from natural ecosystems because they are human constructs and as such managed for agricultural goals (Rapport 2004). In its general sense, it is a way of perceiving agriculture from a systems perspective that emphasizes the connections between the environment and production (Xu and Mage 2001).

The concept of a system defined in various ways depending on the objective and interest of the individual researcher. The system, here, is an assemblage of elements of the system that delimited by a boundary. The elements within each system have a strong functional relationship with each other but restricted, weak or nonexistent relationships with elements in other assemblages of the system. An essential element of a system approach to agriculture is its effect of spatial scale (Conway 1985). Based on the hierarchical theory of system analysis, agroecosystem defined at different scales ranging from field plots to the entire globe (Kast and Rosenzweig 1972; Conway 1985; King 1993).

Climate and agricultural are highly interconnected, and one influence the other in many ways. Climate variability and change affects agriculture through changes in average temperatures, rainfall, and weather extremes (drought and heavy rains); changes in pests and diseases conditions; changes in sea level; and changes in ecosystem services (benefits humans derive from ecosystems) at many scales among other (MEA 2005; Tscharntke et al. 2005; Niang et al. 2014). On the contrary, Agriculture contributes to climate change on a global scale through emission of greenhouse gases (GHGs) (Niang et al. 2014). The observed effects of past climate trends on crop production are evident in several regions of the world, with negative impacts being more common than positive ones (Porter et al. 2014).

Spatially, the tropical highland regions are among the areas most vulnerable to climate change (IPCC 2014; Porter et al. 2014). The climatic and biophysical conditions of the Ethiopian highlands, where the study sub-basin is located changes so dramatically over short distances. As a result, climatic parameters like temperature, precipitation, and others change accordingly. The changes in climatic parameters affect the type of crop to be grown and the socio-economic condition of the people residing in different agroecosystems. It also creates a challenge for policy-relevant implementation of the LVI-IPCC framework in all places of the nation (Simane et al. 2013).

In Ethiopia, of the different sectors, the impact of climate change worse on agriculture, as the sector heavily relies on seasonal rainfall, and where adaptive capacity is perceived to be low (NMA 2007; IPCC 2007a; World Bank 2008). The sector also has unique potential contribution to stabilize the world's climate, through better management of crops, land and livestock, in a way that reduces emissions and increases carbon sequestration in plant biomass and soils (CRGE 2011; FAO 2016).

Like other sub-Saharan African countries, agriculture is by far the most important sector of the economy in Ethiopia; accounting about 38.5% of the Gross Domestic Product (GDP), 85% of the employment, 90% of the export earnings, and 80.2% of the populations' earnings coming from this sector. It is also the major source of food for the population and hence the prime contributing sector to food security (NMA 2007; World Bank 2008; MoFED 2010; Central Statistical Agency [CSA] 2013; National Planning Commission 2016).

However, this sector has been threatened and being affected by climate variability and change. In the last 50 years, the average annual minimum temperature has shown an increasing trend of 0.2^{0}C per decade (EPCC 2015). NMA/National Metrological Agency (2007) also revealed that temperature has been warming by about 0.37 ^{0}C every ten years over the past 55 years. The nation's rainfall characterized by seasonal and inter-annual variability (Conway 2000; Seleshi and Zanke 2004; EPCC 2015). According to Kindie et al (2016), the annual rainfall variability in most part of the country remains above 30%. The part of the nation that experiences higher rainfall variability also has relative higher probability of crop failures. The Belg season is suffering from greater rainfall variability, unreliable onset of the season, and frequent crop failures than the Kiremt season (Kindie et al. 2016).

Considering the importance and susceptibility of the sector, to climate variability and change and accordingly to avert the situation, it is crucial to study the sub-basin spatially. Since climatic and biophysical conditions change so dramatically over short distances in the Ethiopian highland regions, where the study sub-basin located, and creates a challenge of identical policy recommendation to avert the situation (Simane et al. 2013). Therefore, this study attempts to bridge the gaps of knowledge in Fincha sub-basin of the Blue Nile basin of Ethiopia.

The rationale behind for mapping agroecosystem as a unit of analysis is because AES is an intersection of a set of agriculturally relevant climatic factors; soils and physiographic variables relevant to crop production; and a prevailing set of cropping practices. In addition, the classification provides a background for adaptation analysis that takes into account the geographical differentiation (climate, topography, soils, farming systems) as well as the socio-economic stratification of the agricultural sector of the study area. The result of the analysis inevitably revealed a remarkable degree of differentiation in terms of constraints, opportunities, production orientation and socio-economic characteristics of farmers residing in different agroecosystem.

2.2Methodology

2.2.1 Overview of the Agricultureal system of the sub basin

The study methodology includes review of relevant documents and visits to relevant organizations and offices in the region. Relevant literatures including study reports, strategic documents, periodicals, journals, socioeconomic baseline survey reports that have relevance to crop production and land management were thoroughly reviewed. Information were also collected through household surveyes, focus group discussions (FGDs), KIIs, consultations with key officials, and discussions with wereda experts, development agents, farmers, and other key informants, and analysis of existing secondary data and maps.

2.2.2 Agroecosystem Analysis

In this application, the Agroecosystem Analysis (AEA) methodology of Simane et al. (2013) tailored to the conditions of the communities and research relationship in Fincha Sub-basin. According to Simane et al. (2013), the structure of an agroecosystem is a consequence of its environmental setting (e.g., climate, soil, topography, various organisms in the area), agricultural technologies and practices, and farmers' social setting (e.g., human values, institutions, and skills).

We used a participatory, interdisciplinary approach to landscape mapping that makes extensive use of objective data but recognizes that the definitions of system boundaries and functional relationships necessarily involve subjective, locally specific judgments about the defining elements of the agroecosystem.

The definition of agroecosystems based on the overlay of three inputs: an agro-climatic zoning based on precipitation and temperature, a soil and terrain analysis, and a map of the distribution of farming systems.

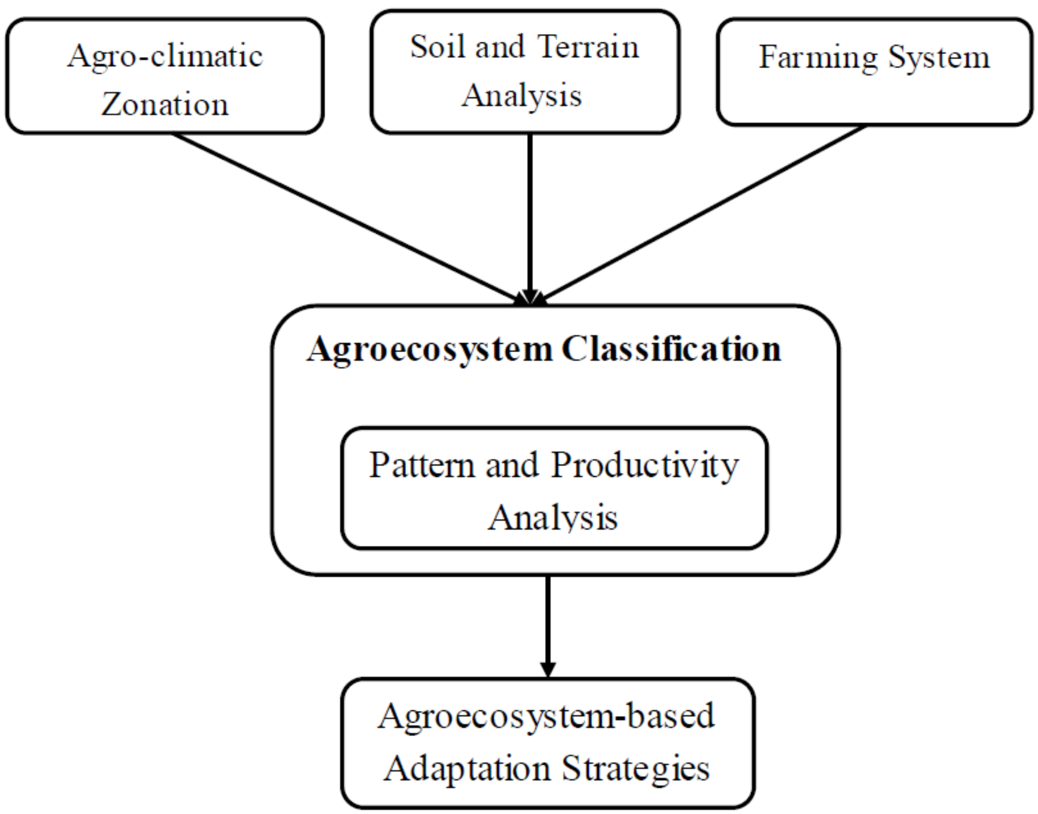


Figure 2-1: Conceptual Framework for agro-ecosystem analysis and adaptation planning in Fincha'a sub-basin adapted from Simane et al. 2014

Specifically, the agroecosystem zones of the Fincha sub-basin defined using the temperature and precipitation ranges associated with the traditional Ethiopian agro-ecological zones (Table 2-1). Soil and terrain analysis performed using the FAO 2006 soil classification in combination with local soil survey. Farming systems defined based on the dominant type of resource base and livelihood pattern of the farm households (FAO 2007) as determined by local agricultural experts and confirmed during the focus group discussion. In most cases, we found that there is a gradual transition from one system to another, so the boundaries between them not actually as sharply defined as they appear on generalized agroecosystems map (Figure 2-4).

Table 2-1: Agro-ecological Zones and their Physical Characteristics

Traditional Zone	Climate	Altitude (m)	Average Annual Temperature (^{O}C)	Average Annual Rainfall (mm)
Bereha	Hot arid	<500	>27.5	<200
Kola	Warm semiarid	500-1500	27.5-20.0	200 - 800
Weyna Dega	Cool sub-humid	1500-2300	20.0-17.5	800 - 1200
Dega	Cool and humid	2300-3200	17.5-11.5	1200 - 2200
Wurch	Cold and moist	Above 3200	<11.5	Above 2200

Source: Agro-ecology zones of Ethiopia, Ministry of Agriculture, Addis Ababa, 2000

Finally, these three sources of information (agro-climatic zoning, soil and terrain analysis, and farming systems) combined to define the major agroecosystems within the sub-basin. Secondary literature used to develop a preliminary structure and criteria for differentiation. There are five traditional agro-ecological zones in Ethiopia (Table 2-1). The traditional zones further elaborated into 33 agro-ecological zones based on temperature, elevation, and length of growing period (Figure 2-3).

Afterward, the differentiated structure refined in collaboration with experts and farmers during my focus group discussions with the communities. This resulted in the distinction of four major agroecosystems.

After defining the agroecosystems pattern, productivity, and sustainability assessment performed. Pattern analysis is the identification of constraints and opportunities for the management of the system, while productivity and sustainability assessment focus on key questions about the functioning of the system, especially with respect to possible ways to overcome constraints to enhance productivity and sustainability to urge possible research and development options. Finally, adaptation strategy for each agroecosystem proposed.

These analyses began with an objective productivity potential assessment based on soil and terrain conditions conducted using the FAO revised Framework for Land Evaluation (FAO 2007). The result of the land suitability evaluation helps to determine the productivity potential of each agroecosystem based on their rank. The hypothesis here is that vulnerability increases with a decrease in crop productivity potential. Then, a full pattern, productivity, and sustainability assessment performed through a series of questionnaires and focus-group discussions (FGD) in consultation with local agriculture experts and complemented by field observations. The assessment includes physical and realizable productivity potentials and existing production constraints used to suggest future adaptation intervention.

2.3 Results and Discussion

2.3.1 Overview of the Agricultural System of the sub basin

Agriculture in the sub basin is predominantly mixed crop-livestock systems, practiced by subsistence farmers on small plots. The major crops grown are tef (*Eragrostis abyssinica*), wheat (*Triticum aestivum*), barley (*Hordeum vulgare)*, sorghum (*Sorghum bicolor*), maize (*Zea mays*), and oats (*Avena spp.*) are among cereals. Faba beans (*Vicia faba*), field peas (*Pisum sativum*), mung beans (*Vigna mungo*) and haricot bean (*Phaseolus vulgaris*) are among food legumes. Noug (*Guizotia abyssinica*), linseed (*Linum usitatissimum*), rapeseed (*Brassica napus*), and sesame (*Sesamum indicum*) are among oil crops. Potato (*Solanum tuberosum*), onion (*Allium cepa*), and garlic (*Allium sativum*) are among horticultural crops grown in the sub basin. Cereals, food legumes, and oil crops are crops grown in descending order of area coverage.

The farming system in the sub basin is dominated by cereal production system that accounts for about 75% of the total cultivated area. From cereals: tef, wheat, and maize account 30.9%, 23.6%, and 19.9% respectively. Most cereal crops particularly tef and wheat are planted on fine seedbed and provided little groundcover during the most erosive storms in July and early August. This is combined with steeply sloping upland area and poor land management practices contribute to the land degradation currently observed in the area.

In the sub basin, the cropping system is also dominantly mono cropping of the first three major kinds of cereal, i.e., tef, wheat, and maize. Intercropping and double cropping practiced in the sub basin to a limited extent. Crop rotation is practiced almost by the entire farmers of the sub-basin. In the area, farmers follow rotations like cereal-pulse-cereal or oil crop-cereal-pulse or cereal-cereal-oil crop or root crops-cereals-pulse or cereal-cereal-pulse.

Farmers of the sub basin use different agricultural inputs (fertilizer, improved seed, pesticide, and herbicide) to increase their level of productivity. In 2014/2015 cropping calendar alone about

87,864 Quintals of DAP and 51,083 Quintals of Urea fertilizers distributed to 58,491 and 48,418 beneficiaries respectively in the sub basin. During the same period, 18,967 improved seed (Maize) distributed to 48,418 participated farmers. In the same year, 9453 liters of 2-4D herbicide and 1846 actinic pesticide distributed to 9306 and 11998 participant farmers respectively (Horo Guduru Wollega Zone Agriculture and Natural Resource Office [HGWZANRO]). Farmers in the sub basin mostly practice hand weeding to control weeds. Weeding frequency can range from one to four depending upon the level of infestation and the crop type. They give priority to tef, maize, wheat, and potato. It is obvious weed cause damage at an early stage of crop growth but farmers unable to exercise timely weeding due to labor shortage because of overlapping of agricultural activities.

Of the major crops grown in the sub-basin, mainly Niger seed, sesame, mung bean, and tef are cash crops and the others used for home consumption while also sold. Oxen used as traction power for land preparation. Land preparation, weeding, and harvesting are the most laborious agricultural activities and they are activities that wealthier households will pay for. Ball worm, termites, and stock borer are the main pests that affect crop production. Ball worm affects Niger seed, termites affect all types of crops and stock borer affects maize. Niger seed ball worm is a pest unique to the sub-basin. Agriculture is predominately rain-fed. An insignificant amount of land is currently under irrigated agriculture whereby traditional irrigation schemes have the dominant share. Rainfall variability is the dominant phenomena that affect agricultural activities. Comparison of the average current yield and the potential attainable yield of major crops of the sub basin also analyzed. The result of the analysis revelead that overall crop productivity in the sub basin is increasing, however, the average productivity of different crops is much less than the potential productivity (Table 2-2).

Table 2-2: Comparison of the average yield and the potential attainable yield of major crops of the sub-basin

Crop	Proportion (%)	Current Yield (T/ha)	Potential yield (T/ha)	Yield Gap (%)
Maize	15	3.11	4.5	30.9
Tef	23.3	0.90	2.0	55
Wheat	17.7	1.83	3.5	47.7
Barley	9.0	1.6	2.2	27.3
Niger seed	7.4	0.55	0.6	8.3
Faba bean	5.9	1.02	2.0	49
Average		1.5	2.5	40

Source: Survey result; Zonal & District agricultural Offices; EIAR bulletins

The Natural resource degradation namely degradation of land, water and vegetation resources and environmental concerns are the most pressing issues in Fincha Sub-basin that affecting the livelihood of its population and overall sustainability of the agroecosystems. One of the root causes of land degradation assumed to be deforestation. The extent of the forest degradation especially severed in the Ethiopian highlands to which Fincha Sub basin belongs (Hurni et al. 2010). The land degradation problem caused on-site and off-site effects on agriculture and water reservoirs found in the sub-basin. It also challenges the desire of farmers to meet the basic food requirements of the growing population currently let alone the food demand of the future generations.

Furthermore, erosion, unreliable rainfall, unimproved agricultural technology, small size land holding and fragmentation, insufficient supply of agricultural inputs (fertilizers, improved seeds, and pesticides), lack of sufficient feed (fodder) for livestock, low performance of local breeds, inadequate veterinary service & high prevalence of animal diseases are some of constraining factors that adversely affect agricultural productivity. Climate change is also contributing to these challenges. Moreover, the inconvenience of rural feeder roads to access input-output market is also a problem (HGWZANRO).

Poor and inappropriate land management is the main cause of physical, chemical and biological degradation of cultivated land, grazing lands and forestland. In the sub basin, there is continuous stress on the limited land resources as up to 90 percent of the population depend on natural resources for their livelihood. In addition, the three hydroelectric dams and their associated reservoirs took much of the grazing and agricultural lands (MoWIE 2014; Buzayehu 2006).

Generally, there are four seasons in the sub basin: “Genna” is the main rainy season extending from June to August; “Bona” is the period that extends from December to February; “Arfasa” the short rainy period lasts from March to May, and “Birra” is the season stretching from September to November (Figure 2-2). The agricultural year in the sub basin begins with preparing and clearing the land for planting of maize in the month of May. The consumption year begins in October with the green harvest of maize (midland, wetland and lowland AES) and barley in highland AES. Genna (June to September) rains are used for planting short cycle crops (tef and wheat) while Arfasa (March to May) rains are used for land preparation and planting of long cycle crops (maize and sorghum). Maize planted in May and harvested in December and January. The planting, weeding, and harvesting periods of tef and wheat crops are in July, September to October, and December respectively. Cattle, sheep, goats, horse, donkey, mule and chickens are the main types of livestock raised in the sub-basin. Horo Guduru cattle breeds are one of the most productive breeds in Ethiopia. Animals free graze on bushes, shrubs, leaves, grasses and crop residues.

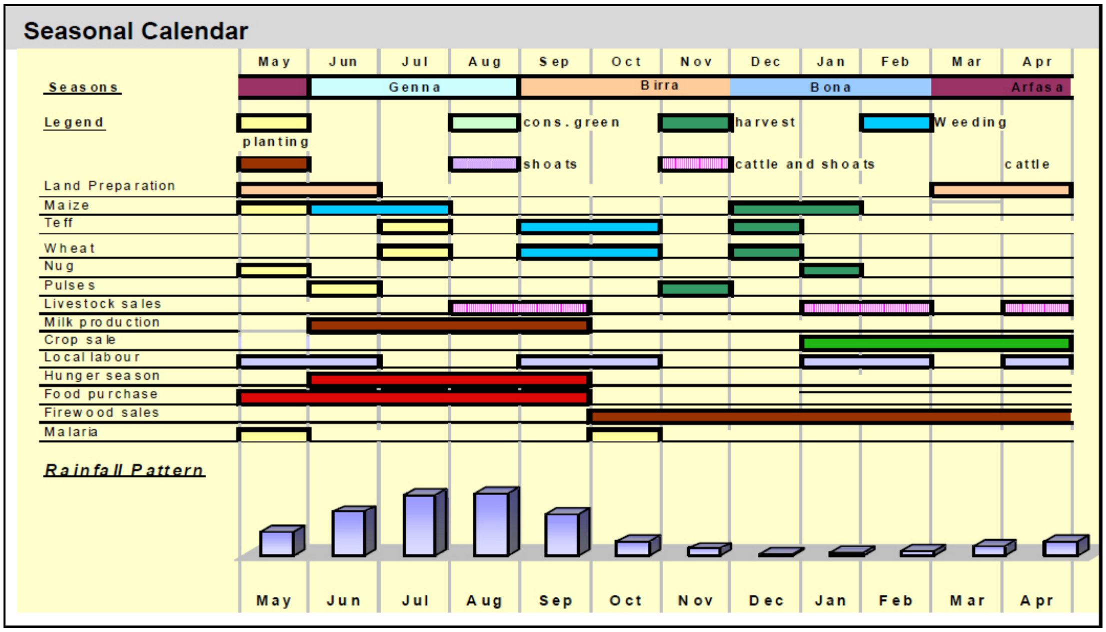


Figure 2-2: Tipical Seasonal Calendar of Fincha'a sub basin

Land, livestock ownership and household size are determinants of wealth. Land holdings for better-off households are about double that of very poor households. All households cultivate the same crops, but receive differing yield mainly as a function of the amount of land cultivated and access to inputs. The ownership of livestock increases across the wealth group. All wealth groups own chickens and sheep. The poor, middle and better off also own cattle, oxen and goats. Only the middle and the better off own horses. The very poor do not own oxen and as a result produce fewer crops. Very poor households will exchange two days labour with the wealthier households in order to use a pair of oxen for one day. Factors constraining wealthier households from owning more livestock are the lack of grazing land and labour as well as the prevalence of livestock disease. Households try to overcome these constrains by feeding animals crop residue, employing shepherds from poorer households and purchasing livestock drugs. Poorer households do not keep more livestock because they lack the income to purchase additional animals.

2.3.2 Definition of Agroecosystems

The analysis of the study identified four major agroecosystems (Highland with sloping terrain AES, the Midland with rolling plateau AES, the Wetland (seasonally waterlogged) with the artificial lakes AES and the Lowland AES) within the study sub-basin (Figure 2-4). The identified AES show a notable difference in terms of agro-ecological zones, dominant sources of livelihood, production potentials, constraints, and production orientations (Table 2-3). The variety of agroecosystem grants both an opportunity and challenge for adaptation to climate change (Simane et al. 2013). The multiplicity of climate conditions suggests that variety of farming techniques, growing different crops, and strategies are active within the region, providing a broad foundation for adaptive efforts, but that same diversity makes it difficult to establish climate change projections and adaptation strategies that targeted to address to these highly localized specific conditions.

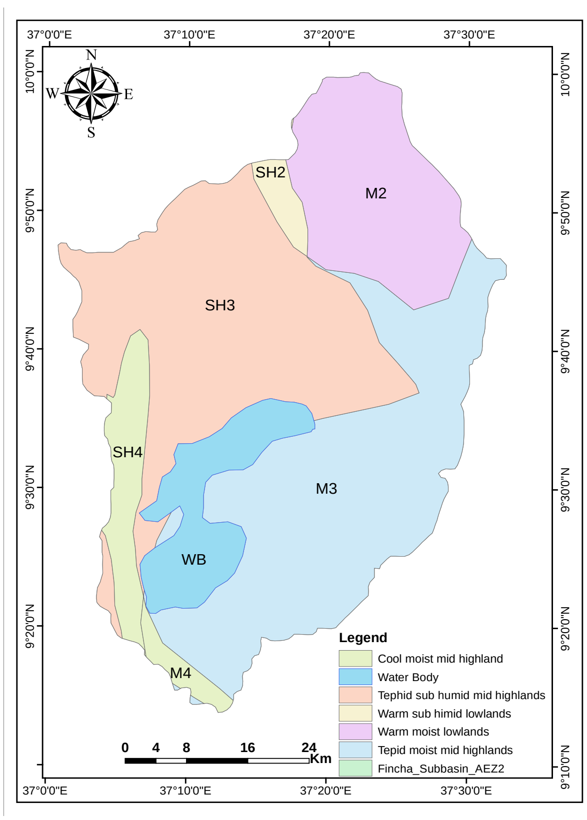


Figure 2-3: Elaborated Agro-ecological Zones of Fincha'a Sub basin

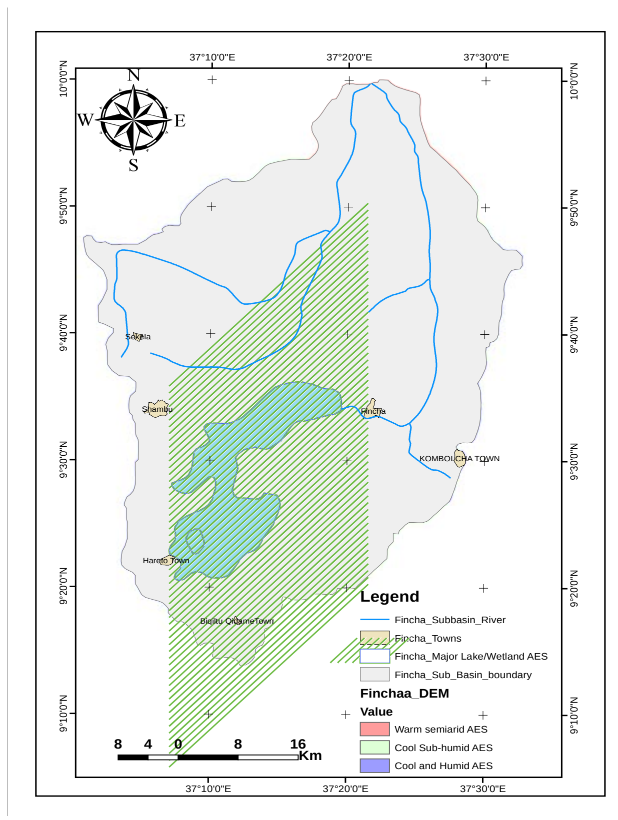


Figure 2-4: Agroecosystems of Fincha'a Sub basin

Table 2-3: Fincha'a Sub-basin Agroecosystems and their characteristics

Agroecosystem (AES)	Farming Systems	Traditional Climatic Zone	Major Soils	Major Crops
Highland	Semi-intensive Barley-Wheat based	Dega	Leptosols Luvisols	Barley, Wheat, Fave Bean
Midland	Intensive Teff-Maize-based	Upper Weyna Dega	Leptosols Nitosols	Tef, Maize, Niger seed
Wetland	Intensive Teff-Maize-based	Lower Weyna Dega	Nitosols	Tef, Maize
Lowland	Sorghum-based extensive	Upper Kola	Luvisols Vertisol	Sorghum, Tef, Sesame

Source: Own field research data and other sources

The four identified agroecosystems (the Highland with sloping terrain AES, the Midland with rolling plateau AES, the Wetland with the artificial lakes AES and the Lowland AES) discussed below.

2.3.2.1 The Highland with sloping terrain AES

This AES confined to the watershed ridge above 2,300masl in the Dega Agro-ecological Zone. Typically, the AES experiences cool and humid type of climate. It is characterized by steep (15% to 30%) to very steep (> 30%) slopes. In terms of area coverage, it accounts about 21.9 % of the sub-basin. Formerly, the area is known for its overall high production potential, fertile soil, and producing surplus food. However, the high rate of deforestation, soil erosion, and landslide are the major environmental problems that jeopardized the overall productivity of the AES.

Temperature ranges from a minimum of 10-15^{0}C (June to August) and maximums of 15-25^{0}C (January to March). Agriculture dominated by rain-fed production system and takes place only during the Genna (Kiremt) season. Previously Arfasa production of Barley known in the area but now such production is minimal or even non-existence in the area due to changes in climate.

The main crops grown in this AES are barley, wheat, pulses, and potatoes. In terms of area coverage, wheat and Barley accounts 35.1% and 26% respectively. Previously, some 20 to 30 years back, crops like Tef, Maize, and Nuge not grows in this AES, but now the community started to grow these crops. As verified during focus group discussion, this is one indicator of climate change (temperature increase). Wheat, barley, pulses, and potatoes are used both for home consumption and sold. Land prepared using oxen plows and by hand digging. The most laborious agricultural activities are weeding and harvesting.

The main crop pests and diseases are ball worm, leaf blight, and smut. Crops affected by ball worm are barley, wheat, and tef; crops affected by leaf blight are potatoes and tef; smut attacks wheat, barley, and maize. Timely weeding reduces the impact of leaf blight. Removal of affected plants is a treatment practiced to reduce the impact of smut. In this AES farmers use fertilizer to a limited extent rather use compost to manage the fertility of their soil.

The main types of livestock owned are cattle, shoats, and equines. Animals free graze on browse and fed crop residue. Rivers are the major source of water for both people and livestock in dry and wet seasons. There is no payment for water. Cows are the only animals milked in this AES. Shoats older than one year, cattle older than two years, butter and eggs sold to generate income. Boys are responsible for looking after livestock. The main diseases affecting livestock are anthrax (cattle, shoats), blackleg (cattle), Pasteurellosis (cattle, shoats) and African horse sickness (equines).

2.3.2.2 The Midland with rolling plateau AES

This agroecosystem dominantly characterized by midlands or Weina dega areas with an extensive rolling plateau, ranging in altitude between 1800 m and 2300 m.a.s.l. The topography is predominantly undulating land and plains. Coupled with opportunities for market access, this livelihood zone is food self-sufficient. It covers 44.7% of the total area of the sub-basin. The main rainy season extends from early May to the end of September. Average annual rainfall ranges from 1200mm-1800mm. Maximum temperatures of 23-27 ^{0}C reached from January to March. Minimum temperatures of 7-15 C^0 are normal from October to November. Soil types are dominantly loam and silt, sand and clay, which are fertile. Generally, the AES can be considered as a very high potential area and annually produce a food surplus.

Tef, Niger seed, Maize, Wheat, Barley, and Beans produced very well in this AES. In terms of area coverage tef, wheat and Niger seed account 26.2%, 25.7%, and 18.5% respectively. Households grow tef, maize, and wheat for consumption and sale while Niger seed grew as a cash crop. Land preparation, weeding, and harvesting of cereal crops are the most labor-intensive activities. The main crop pests and diseases are ball worm, leaf blight, and smut. Crops affected by ball worm are barley, wheat, and tef. Crops affected by leaf blight are potatoes and tef; smut attacks wheat, barley, and maize. Timely weeding reduces the impact of leaf blight. Removal of affected plants is a treatment practiced to reduce the impact of smut. This agroecosystem utilizes more agricultural inputs such as improved seed and inorganic fertilizer than the adjacent AES.

Cattle, goats, sheep, and chickens are the main types of livestock raised. Animals free graze on grasses, bushes, leaves and crop residues. Water sources for the animals include springs, minor rivers and seasonal ponds in wet seasons and major rivers during the dry season. Water sources for humans include springs, dug wells, rivers, and hand pumps. Cows are the only animals milked. Men and boys are mostly responsible to take care of livestock's. Trips, internal parasite, and pasteurellosis are the main pests and disease affecting livestock.

The key sources of income are crop sales, livestock and livestock product sales, agricultural labor and petty trade. Cereals like maize, wheat, and tef sold as well as used for consumption whereas crop like Niger seed grew exclusively for sale. Wealthier households also sell barley and pulses (beans and field peas). The honey production also earns income for some households. All wealth groups sell cattle, sheep, and chickens. Middle and better-off households also raise and sell fattened oxen. Livestock product sold by all wealth groups refers to eggs and butter.

2.3.2.3 The Wetland (seasonally waterlogged) with the artificial lakes AES

This agroecosystem includes the wetlands and the associated artificial lakes constructed for the generation of hydroelectric power. According to Ramsar wetlands definition of (1997), Wetland is an ecosystem that occurs when the water table is at or near the surface of the land, or where the land covers by shallow water. Therefore, it includes areas of marsh, fen, peat land or water, whether natural or artificial, static or flowing, fresh, brackish or salt including areas of marine water the depth of which at low tide does not exceed six meters. Of the different wetlands, the seasonally waterlogged areas provide the best potential for agricultural practices. Crops like Teff, Maize and horticultural crops grow best in this agroecosystem by draining the water. In terms of area coverage, tef and maize account for 43.2% and 36% respectively. Households grow Tef, Maize and horticultural crops for consumption and sale. The main crop pests and diseases are ball worm, leaf blight, and smut. Households use fertilizers, improved seeds, insecticide/

herbicide and compost. Mostly, improved seeds, fertilizers and insecticides/herbicide obtained from the farmers' cooperative and Bureau of Agriculture and Rural Development (BOARD). Land preparation, weeding, and harvesting of cereal crops are the most labor-intensive activities.

Recession farming is another important activity exclusively carried out in this agroecosystem. Recession farming is a crop production system carried out by residual soil moisture that is stored in the subsurface after annual inundation of floodplains, lake margins or seasonal wetlands. This farming system practiced at the floodplains and associated artificial lakes constructed for the generation of hydroelectric power using the residual moisture retained when the lake's water recedes.

Cattle, goats, chickens, sheep, and equines are the main types of livestock raised. Animals free graze on bushes, shrubs, leaves, grass, and crop residues. Water sources for the animals include minor rivers and seasonal ponds in wet seasons and major rivers during the dry season. There is no payment for livestock food or water. Water sources for humans include springs, dug wells, rivers, and hand pumps. Cows are the only animals milked. Livestock products sold include eggs, butter, and skins. Taking care of livestock is left mostly to men and boys. Trips, internal parasite, and pasteurellosis are the main pests and disease affecting livestock.

The wetland agroecosystem generally accounts for about 15% of the sub-basin (MoWIE 2014). These ecosystems act as an interface between land and water and have a wide socioeconomic and ecological function. However, communities are complaining about the construction of the artificial lakes constructed for hydropower generation that has taken their grazing and farmland. As compared to the other agroecosystem found in the sub-basin the households in this AES holds relatively small land holdings.

In this AES, there are also villages that are isolated from the land mass due to the inundation of the Fincha reservoir. These islands have very poor boat transport to go to the nearby towns like Fincha wuha. The boat transport system is very expensive particularly to school boys and girls who are paying two Birr every day to reach their schools. Communities also get all market and health services by crossing the water with the boats.

Another important problem associated with this AES is the problem of wetlands degradation that includes siltation due to soil erosion, and overexploitation of wetlands to farming activities due to dwindling of farmland (shortage of land). The siltation of the reservoir inundated the adjacent land that also escalated the grazing land shortage, and communities consider this ecosystem as a lost land. The implications of wetland degradation resulted in Flooding, declining water quality, declining wetland biodiversity, declining water table and water recharges. There are also opportunities to halt the situation by controlling soil erosion in upland areas, improve productivity in dry land agriculture, practicing rice cultivation in the seasonally flooded plains, strengthen policy for protection/conservation of wetlands, protecting water sources and benefiting the communities from such development activities.

2.3.2.4 The Lowland AES

The warm semiarid AES confined to the lower parts of the sub-basin along the Blue Nile gorge with an altitude range less than 1800 m.a.s.l. in the Kola Agro-ecological Zone. Typically, the AES experiences a hot type of climate. This specific AES accounts 18.4% of the sub-basin. Landslide and high rate of soil erosion are the major environmental problems of this AES.

The production of sorghum, maize, tef, sesame and mung bean (Masho) crops best known in this agroecosystem. In terms of area coverage, sorghum is the first and accounts 35.8%. Households grow Sorghum and Maize for home consumption while Sesame and Mung bean grows as a cash crop. Termite, Stock borer, and Smut are pests affecting crop production in this agroecosystem. Land prepared using oxen plows and by hand digging. The most laborious agricultural activities are weeding and harvesting.

The main types of livestock owned are cattle, shoats, and equines. Animals free graze on browse and fed crop residue. Rivers are the major source of water for both people and livestock in the dry and wet seasons. Cows are the only animals milked in the AES. Shoats older than one year, cattle older than two years, butter, and eggs sold to generate income.

According to the data obtained from the Hababo Guduru District, there are five investors in this AES with a total capital of 5,687,000 Birr. The investors are engaged in agricultural activities and owned a total of 606 hectares. The job opportunity created by the investors includes 11 permanent and 186 temporary peoples.

Apart from other AES, the upper part of this agroecosystem utilized for commercial sugarcane plantation. The source of irrigation water for the sugarcane plantations are Fincha and Neshe dams after generating the hydroelectric powers. According to sources from Fincha Sugar Factory, the command area of the farm is 67,098 hectares. In 2017, sugarcane production carried out on 19,559 hectares of land.

2.3.3 Pattern Analysis

Pattern analysis deals with the identification of Constraints and Opportunities for the management of the system. The constraints and opportunities of each of the agroecosystem identified and presented below.

2.3.3.1 Constraints of the agroecosystems

1. **Highland AES:** Some of the major agroecosystem specific constraints include

Land degradation/ Soil erosion is a phenomenon resulting from unsustainable land management practices including inappropriate cultivation, mono cropping, deforestation, overgrazing and cultivation on steep lands due to population pressure, is a major threat to the environment in the AES, as well as to livelihoods, where the majority of people directly depend on agricultural production. The effect of soil erosion not limited to onsite effects like yield reduction, soil depth reduction, soil water holding capacity reduction, etc but also offsite effects such as sedimentation in reservoirs and causes pollution on water bodies.

Furthermore, the problem of land degradation leads to direct effects (reduced production & food insecurity; migration and social conflicts; high soil erosion rates and reduced soil fertility; increased sediment load affecting the downstream dams and reservoirs; reduced water supply and quality; and loss of biodiversity) that eventually brings poverty and breakdown of ecosystems. The direct causes (pressure) for this are improper cultivation practices, deforestation, overgrazing, and cultivation on steep slopes due to population pressure and climate change. The drivers or indirect causes are both socio-economical and biophysical.

Soil types: The steep slopes of the AES are underlain by Leptosols, which are shallow and often gravelly with low water holding capacity. They are very prone to erosion and any further soil loss might lead to reduced soil productivity, threaten farmers' food security, and increase offsite reservoir sedimentation.

2. **Midland AES:** some of the major specific constraint in this AES include

Soil Acidity: The problem of soil acidity is increasing from time to time, is a major constraint on production, and needs to reclaime the soil. In order to improve the productivity of acid soils, the regional government has initiated a liming program.

Crop residue burning: such a practice is common in this AES of the sub-basin. The practice has a negative effect on soil microorganisms.

Farming System: in this AES, the farming system is entirely dominated by annual crop production system that accounts almost the entire cultivated area. Soil erosion by water is very high from annual crops than perennial crops (Hurni 1988). Most cereal crops particularly tef and wheat are planted on fine seedbed and provided little groundcover during the most erosive storms in July and early August. This combined with poor land management practices contributes to land degradation currently observed in the area.

3. **Wetland AES**: some of the major constraints in this AES include

Water logging: the Wetland AES is prone to water logging problem. Such problems are hindering the full productivity of the land. Appropriate technology capable of utilizing the water logging of the soil recommended for practice.

Flood inundation: the land degradation problem of highland AES causes flooding and siltation of the agricultural fields in this AES. The problem caused by the decrease in infiltration and increase in surface runoff. Such a problem also causes decrease in base flow of the rivers during dry season.

Small land holding: As compared to the other AES, the per capita land holding in this specific AES is relatively small (Tessema and Simane 2019). The problem arises because of the hydroelectric dams constructed in the area.

4. **Lowland AES**: some of the constraints in this specific AES include

Deforestation: Forests have tremendous present and future values to human beings existence. Forests are important for maintaining ecological balance and preserving the life supporting system of the earth. They are the largest ecosystems and have the following generalized functions viz. production function (economic function); protective or amelioration function (ecological function) and development function (MEA 2005). However, forests of the sub-basin threatened by many factors majorly conversion to agricultural land use, and land and water intensive development activity carried out in the sub-basin by the government (Bezuayehu and Sterk 2008). Even though the problem of deforestation is a common practice in the sub-basin the recent practice to obtain agricultural fields for the production of sesame in the Lowland AES, cause a devastating impact in the forest resources of the AES.

Climate change: Agriculture, particularly rain-fed agriculture, is extremely sensitive to climate change (Ramay 2011). The main direct effects of climate change will be through changes in factors such as temperature, precipitation, length of growing season, and timing of critical events related to crop development (Agarwal et al. 2000). Like other rain-fed dominated agricultural systems, Fincha Sub-basin agricultural system is also highly vulnerable to the negative impact of climate variability and change. Participatory agroecosystem analysis indicates that sensitivity to climate variability and change is a major concern in all defined AES. Especially, the Lowland AES have faced on average 3.6 years drought and 3 years flooding in the past 20 years (Tessema and Simane 2019).

Limited access to improved seed technologies: The use of improved seeds has multitude advantages to increase productivity, produce a large amount of biomass, increase resistant to diseases, pests and weeds, and fasten vegetative growth and provide early land cover. However, due to limited access, the use of improved seeds crop varieties is extremely low which is less than 20% of the total cultivated land. Other than maize, the coverage of other crops in terms of improved seeds utilization is almost nothing. Even though, the problem is in all AES, this specific AES is suffering a lot as compared to the others (Tessema and Simane 2019).

2.3.3.2 Opportunities of the agroecosystems

The opportunities found in the specific agroecosystems for the management of the system includes but not limited to the following:

1. **Highland AES:** The major opportunities in this specific AES includes the following:

Introducing temperate fruits and cool season vegetables: The temperate fruits are adapted to temperate zones. However, there are some varieties grown very well in the tropics under certain climatic condition. The most important fruits in this group are apples, pears, plums, nectarines, and strawberry. Furthermore, low chilling requiring varieties found adaptable at Holetta, an area with a similar climatic condition like the study area, are available (Gebre 2004). The Highland AES are convenient for temperate fruits and cool season vegetable production. Since low temperature experienced in some months (October-January) of the year satisfies their chilling requirement. Therefore, it is possible to utilize this untapped potential for the benefit of the community as well as the nation. Currently, in Ethiopia temperate fruits are grown at an altitude of 2200 masl and beyond up to 3000 masl (Gebre 2004).

Indigenous Sustainable Land Management Practice (SLM): For generations' farmers in the sub-basin practiced indigenous SLM practices to halt land degradation, improve soil productivity and for woody biomass production. In Ethiopia, as population increased, some of the indigenous practices such as fallowing, manuring, crop residue management, and leaving trees on farmland declined due to high demand for fuel wood, feed and house construction (Zeleke et al. 2006). However, in the sub-basin, there are still indigenous knowledge practices practiced by farmers that can assist to manage the natural resources including land sustainably. Some effective SLM practices already exist and could be scaled-up, but this can only be done with serious investments in building the knowledge base and developing technology.

In the subbasin one traditional unique practice that not common elsewhere is the practice of <<Chichessu>>. Chichessu is analogous to fertilize with manure. It is a local name given to the traditional soil fertility management prevailing in the sub-basin. Another important common SLM practice in the sub-basin is the traditional agro-forestry practices in the form of scattered trees on the farmland and home garden. Peoples used to plant both indigenous and exotic tree species for such purposes.

Natural/assisted re-generation of degraded lands–enhance vegetation cover of degraded lands through afforestation/reforestation initiatives. Soil erosion in this AES is a well-recognized problem, identified as a priority by the local community members. Therefore, this can be utilized as an opportunity for intervention.

2. **Midland AES:** the major opportunities in this specific AES include:

The practice of using Agricultural Input: Agricultural inputs believed to be the most important factors to increase agricultural productivity. In terms of using agricultural inputs (fertilizer, improved seed, pesticide, and herbicide), farmers of the sub-basin have a long tradition. Particularly, this specific AES is the largest agricultural input user.

Livestock production systems: promote diversified animal feed production (high quality grass & fodder species); support effective feeding systems compatible to existing farming practices (restricting free range grazing with cut and carry); optimize herd size (support destocking through improved and adapted breeds); promote consumption of lower emitting sources of protein (e.g. Poultry production); enhance beekeeping activities in rehabilitated areas.

Integrated Soil Fertility Management (ISFM) systems: It aims at managing soil by combining different methods of soil fertility amendment together with soil and water conservation. It takes into account all farm resources like the use of organic sources of fertilizer; reduce the loss of nutrients; and judiciously using inorganic fertilizer according to needs and economic availability.

Growing of diversified crop species: Diversified crop species are growing in this AES as compared to the other AESs (Tessema and Simane 2019). Therefore, it requires utilizing them as an opportunity for increasing agricultural production of the farmers.

Marketing opportunities: as compared to the other AESs, this agroecosystem has the relative advantage of access to market.

3. **Wetland AES:** The specific opportunities in this specific AES include:

Rice-based production system: In some of the seasonal waterlogged or flooded areas, rice can be an important crop to grow. However, the utilization of such potential not currently practiced in the area that has the potential to increase the crop production potential of the specific AES.

The seasonally waterlogged areas provide the best potential for development. The shallow water table is continually recharged from the lake and permanently waterlogged grasslands. For rainfed and irrigated cropping shallow drainage would be required. The shallow water table could provide water for supplementary or full irrigation in the dry season. With or without drainage this grassland could be used for improved forage production.

4. **Lowland AES:** the specific major opportunities includes

Production of Mung bean & Sesame: These two crops are important cash crops even at the national level. Therefore, the production of these crops is a good opportunity for farmers of this specific AES.

Relatively larger land holding: As compared to the other AESs, the per capita land holding in this specific AES is large (Tessema and Simane 2019). Therefore, this can be possibly utilized as an opportunity for different development activities.

2.3.4 Productivity Analysis

At the production level, agricultural productivity measures the value of output for a given level of inputs. To increase agricultural productivity, the value of output must increase faster than the value of inputs. Gains in overall agricultural productivity can, therefore, come from changes in the production process that produce more output per unit of land or labor, or from changes in production and market costs and hence the increased profitability for farmers. Generally, increasing agricultural productivity not only relies on improved production efficiencies; but also on factors such as adequate access to productive resources, well-functioning markets and infrastructure, and policy promoting economic and social stability (Simane et al. 2013). □

In this subtopic, to determine the productivity potential of each agroecosystem, we conducted the land suitability evaluation that represents the suitability of different AES for crop production. Suitability is then ranked on a scale from one (least suitable) to five (most suitable) (FAO 2007). Simane et al. (2013) in Choke mountain watershed used the same scale. Here we hypothesized that vulnerability increases with a decrease in crop productivity potential, as household livelihoods are more at risk from substantial changes in climate. Then the suitability of soil characteristics and overall average suitability to agricultural production by AES done and presented in Table 2-4. The relative suitability of land areas for agriculture includes climate, soil (fertility, depth, drainage, & texture), and terrain conditions relevant to agricultural production.

The result of the analysis showed that the midland AES is the most suitable interms of soil characterstics (depth, natural fertility, drainage, & texture) and overall average conditions for agricultural production. While the lowland AES is the least suitable interms of soil characterstics and overall average conditions for agricultural production. The wetland and highland AESs scored more suitable and suitable results respectively. In terms of terrain condition, the wetland and midland AESs ranked as not constrained and slightly constrained, where as lowland and highland AESs scored as constrained and severely constrained respectively (Table 2-4).

Table 2-4: Analysis of the suitability of soil characteristics and overall average conditions to agricultural production by AES

AES	**Depth ***	**Natural Fertility***	**Drainage***	**Texture ***	**Terrain***	**Average Suitability****	**Dominant Constraints**
AES1	3	2	2	2	5	3	Land degradation, Erosion
AES2	2	2	1	1	2	5	Soil Acidity
AES3	2	3	5	2	1	4	Water logging, Siltation, liability to Flooding □
AES4	4	3	1	3	4	2	Rainfall variability, fragmented and steep slopes with the highest degradation rate

AES1: Highland; AES2: Midland; AES3: Wetland; AES4: Lowland
For soil characteristics*: 1: not constrained; 2: slightly constrained; 3: moderately constrained; 4: constrained; 5: severely constrained.
For average suitability**: 1: not suitable; 2: least suitable; 3: suitable; 4: more suitable 5: most suitable.

Comparison of the average yield of the local and improved seed variety for three major crops of the sub basin also analyzed in terms of specific agroecosystem. The result of the analysis presented in Table 2-5 below with their standard deviation. This is also another important indicator of the condition of agricultural production potential of each of the agroecosystems.

Table 2-5: Average yield (tones/hectare) & standard deviation of yield (in parentheses) for three major crops in Fincha'a sub basin agro-ecosystems

AES	**Tef**		**Wheat**		**Maize**	
	Local Seed	**Improved Seed + Fert**	**Local Seed**	**Improved Seed + Fert**	**Local Seed**	**Improved Seed + Fert**
Highland	0.7 (0.4)	1.0 (0.5)	1.7 (0.5)	2.2 (0.6)	1.8 (0.5)	2.4 (0.8)
Midland	1.1 (0.5)	1.3 (0.6)	1.8 (0.5)	2.6 (0.7)	2.9 (0.7)	3.8 (1.2)

Weatland	1.1 (0.4)	1.4 (0.5)	1.2 (0.4)	1.5 (0.5)	3.2 (0.9)	4.0 (1.1)
Lowland	0.8 (0.6)	1.1 (0.4)			2.7 (1.1)	3.6 (0.8)
Average	0.9 (0.5)	1.2 (0.5)	1.6 (0.45)	2.1 (0.6)	2.7 (0.8)	3.45 (1.0)

(Source: Own field research data)

Although physical evaluation of productivity done is informative, the relative input utilization of each AES also reflected the potential and possible gap for agricultural crop production systems that observed in the sub-basin (Table 2-6). The observed production system is the result of ecological, socioeconomic and cultural factors found in the sub basin. Relevant management considerations that influence realizable production potential in each AES listed in Table 2-7.

Table 2-6: Input utilization currently practiced in the sub-basin

AES	Improved Seed + Fertilizer (%)	Local Seed + Fertilizer (%)	Local Seed + Compost (%)	Local Seed only (%)	Total Percentage
AES1	14	52.8	20	13.2	100
AES2	21	55	13	11	100
AES3	23.9	48.6	14.2	12.3	100
AES4	12.1	54.2	7.1	28.6	100

Source: Survey result and District agriculture office
Key: AES1: Highland; AES2: Midland; AES3: Wetland; AES4: Lowland

The result of input utilization confirms that most farmers of the sub-basin used local seed in combination with fertilizer as depicted in table 2-6. Out of the total land cultivated in 2017 cropping calendar 52.8%, 55%, 48.6% and 54.2% of the agroecosystems covered by (local seed and fertilizer inputs) in AES1, AES2, AES3 and AES4 respectively. The percentage share of improved seed and fertilizer inputs was 14%, 21%, 23.9% and 12.1% in AES1, AES2, AES3 and AES4 respectively. The result of the analysis revealed that the full productivity potential of the sub-basin not yet utilized.

The assumed intensity of management and the level of agricultural investment expected for physical, chemical and biological constraints on the productivity of each AES confirmed through the focus group discussion and key informant interviews in consultation with the experts presented in Table 2-7 below. Key properties and production potentials identified through agroecosystem pattern and productivity analysis carried out.

Table 2-7: Realizable Potential of Fincha'a sub-basin Agroecosystems

AES	Assumed Intensity of Management	Key properties and production potentials
AES1	Ecological based production system	Production for subsistence plus commercial sale is a management objective. Production based on the use of

	including highland temperate fruits. In addition, use of relatively high level of inputs for a crop like wheat.	both traditional cultivars and improved high yielding varieties; labor-intensive techniques, and practice of application of nutrients for high yielding varieties. The high steeply sloping upland and consequent high erosion hazard prevail but minimum conservation techniques practiced.
AES2	Relatively high level of input & management practices	Production is based on improved high yielding varieties, mechanized, and uses optimum applications of nutrients and chemical pest, disease and weed control
AES3	High level of input & management practice including recession farming	practicing rice cultivation in the seasonally flooded plains, production based on improved high yielding varieties, labor intensive, & optimum application of fertilizer/inputs.
AES4	Relatively low level of input	Production mainly based on subsistence production system. The AES has a high potential for the production of sesame and newly introduced mung bean, which is a good cash crop.

(Source: Own field research data)

Sustainable systems are systems those best use the environmental goods and services while not causing damage to these assets (MEA 2005; Scherr and McNeely 2008). From the crops grown in the sub-basin Tef, Wheat and Maize are relatively higher external input users and Barley, Sorghum, Fava Bean, Field Pea, and Niger Seed are almost none external input users. The decision to use or not the external inputs requires proactive and conscious thinking. The inefficient use of external inputs can cause considerable environmental harm. In contrary, increased agricultural area by encroachment to the natural ecosystem to increase agricultural production contributes substantially to the loss of habitats, associated biodiversity and their valuable environmental services (MEA 2005; Pretty 2007; Scherr and McNeely 2008).

In the study sub-basin, there are two inconsistent interventions carried out by the community. In one hand, you may find picturesque landscape due to the traditional agro-forestry practice dominant in the sub-basin. The practice contributes to the mitigation of climate change by sequestering carbon in the aboveground biomass and below ground in the soil. On the contrary, especially in the Highland AES, the practice of agriculture contributing to the change of climate through carbon emission by encroachments to the natural ecosystem and deforestation and inappropriate land use that aggravated soil erosion. Therefore, it is required to enhance the sustainable practice, recuperate the unsustainable practices and harnessing agro-ecological based production systems.

2.3.5 Adaptation Strategies

It is obvious that adaptation not only involves reducing risk and vulnerability but also seeks opportunities and building the capacity of the agricultural sector and the communities including the natural systems to cope as well as mobilizing that capacity to implement actions (Tompkins et al. 2010). It is inevitable that the business as usual approaches to increase agricultural production no more feasible and requires a proactive approach that continually adapt to the changing environment. Compounding factors including climate variability and change are causing a significant impact on the study sub-basin. Therefore, designing adaptation strategies capable of withstanding the significant challenges in the whole of the sub-basin and specifically in each AES offers the opportunity to benefit from the existing resources and minimizes risks.

Agroecosystem analysis provides opportunities for designing adaptation strategies relevant to the specific AES that considers the spatial differences (Climate, topography, soil and farming system) including the socio-economic stratification of the agricultural sector of the study sub-basin. In addition to climate variability and change, the study sub-basin facing different challenges like land degradation, soil fertility decline, livestock feed and fuel wood that affects the livelihood of the farming communities.

AES specific strategies for climate resilient development in Fincha sub-basin as identified during the household survey, focus group discussion, expert judgment, and review of literatures includes:

Agronomic Sustainable Land Management (SLM) technologies: SLM is vital for enhancing and sustaining the productivity of food and fiber of agricultural systems. It also stated that the highly productive agricultural systems needs sustained and made more efficient to reduce the impact on the environment (World Bank 2006). The use of appropriate crop production technologies could contribute to the integrated effort to arrest land degradation and for sustained productivity. Beneficial farm-level land management practices designed to maintain the quality and long-term productivity of the land and to mitigate environmental damage from crop production.

According to IIRR (2002), Agronomic SLM technologies grouped in to; *Conservation tillage* (includes but not limited to contour plowing, ridging, minimum tillage, tied ridging);

Conservation farming (includes crop rotation, intercropping, alternative crop varieties, fallows and area closure); *Soil fertility management* (includes manure application, compost application, green manuring, and biological nitrogen fixation). The technology is applicable to all AES based on the specific scenario. For example, out of the conservation tillage, technologies like contour plowing & minimum tillage more important to the Highland AES where soil erosion is severe and tied ridging is important in Lowland AES where moisture stress is a problem. Minimum tillage is good on sloping, well drained, and course and medium textured soils, but less effective on poorly drained soils or on soils that form surface crusts easily. Weeds may be a problem at first in minimum tillage. It is necessary to weed more or to use mulch to smother the weeds. It is possible to spray herbicides, but these are expensive and may harm the environment (IIRR 2002). Generally, in the conservation agriculture approach three linked principles achieved viz. minimum soil disturbance, permanent organic soil cover, and diversification of crop species (FAO 2011).

Bio farming: This is a system of establishing permanent agriculture (Permaculture) that draws from several disciplines including organic farming, agro-forestry, integrated farming, sustainable development, and applied ecology. It is an applicable strategy for Highland, Midland & Lowland AES, but with different technology packages in each. The intent of bio farming is to optimize agricultural outputs produced by the community while minimizing external inputs like chemical fertilizer (Simane et al. 2013).

Area closure /Farmer Managed Natural Regeneration: As the major problem in the sub-basin is land degradation, most lands, especially in Highland AES, are at the verge of losing their potential to render further service; so, it is better to manage & reclaim them and take some benefit out of it. By allowing severely degraded and eroded lands to rest, and letting the natural vegetation to recover by itself with passive forest management practice, satisfactory soil conservation and forest product can achieves at a rather slow rate but with almost no input. This procedure of closing off the highly degraded lands for conservation has been termed as area closure or hill closure (Chadhokar 1992). Hill closure denoted as a protection system to improve degraded land with vegetation and/or soil through natural regeneration.

Introducing temperate fruits: Steep slopes characterize the Highland AES of the sub-basin. The high altitude areas are convenient for temperate fruits production (Gebre 2004). Since low temperature experienced in some months (October-January) of the year satisfies their chilling requirement, seed production of cool-season vegetables achieved in such areas. In addition, due to population pressure and the consequent land shortage, farmers are cultivating steep slopes. The cultivation of such lands and planting to cereals definitely degrades the land obviously due to severe soil erosion. In areas where steep slopes put under cultivation, it would be worth introducing fruit tree cultivation that could provide perennial vegetation cover to the soil. The introduction of fruit tree planting in this AES accompanied with intercropping technologies where farmers could produce other leguminous and/or cereal crops in the free space between the fruit trees.

Reduced sedimentation: The soil erosion problems happened because of the steepness of the slope, poor land use system and lack of SLM system that are creating damage to downstream reservoirs, wetlands, and waterways. It has also implications for flooding, decline water quality, declining wetland biodiversity, declining water table and water recharge. Therefore, by avoiding or reducing such problem we need to safeguard uses such as hydroelectric power generation and their implications on the wetland AES (World Bank 2006).

2.4Conclusion and Policy Implications

The agroecosystem analysis of Fincha sub-basin confirmed the considerable challenges posed on each AES. The compounding factors creating a challenge on the agroecosystems include environmental degradation, climate variability and change, population growth, deforestation and inappropriate land use practice are among some to mention. The widespread deforestation, cereal dominated production system that left the farmland without groundcover during heavy and erosive rainfall season (July and August) coupled with livestock free grazing makes the land of the sub-basin vulnerable to erosion and poses serious land degradation that could lead to significant productivity declines.

Furthermore, small sizes of land holding and fragmentation, insufficient supply of agricultural inputs (fertilizers, improved seeds, and pesticides), poor infrastructure to supply agricultural inputs to farmers’ holdings and to access agricultural products to the market and lacks of credit facilities are some of the constraining factors that adversely affect agricultural productivity in the sub-basin.

The challenges and opportunities found in each agroecosystem viewed from a system perspective as interlinked parts in creating specific adaptation strategy to increase the resilience of the system. AES is one method that provides the opportunity to delineate identical areas with similar challenges and opportunities of a landscape. Then the transformation of the agricultural system of each AES by fostering the sustainable intensification of the production has a paramount importance.

The agroecosystem analysis of Fincha sub-basin resulted in a classification of four AES. The potential adaptation strategy recommended for each agroecosystem in consultation with the local community and experts including but not limited to the following. Specifically, for Highland AES permaculture (biofarm system) that includes the temperate fruits, and soil and water conservation techniques; for Midland AES sustainable intensification by including relevant agronomic sustainable land management technologies; for wetland AES sustainable intensification by introducing rice-based production system including the wetland management system; and for Lowland AES extensive agriculture production system by including water retention techniques. Generally, greater integration of the most visible avenues by considering the specific potential to generate a sustainable solution to the development challenges required.

3. VULNERABILITY ANALYSIS OF SMALLHOLDER FARMERS TO CLIMATE VARIABILITY & CHANGE: AN AGROECOSYSTEM BASED APPROACH

ABSTRACT

Ethiopia frequently cited as a country that is highly vulnerable to climate variability and change. The country's high vulnerability arises mostly from climate sensitive agricultural sector that suffers a lot from risks associated with rainfall variability. A vulnerability factor (Exposure, sensitivity and adaptive capacity) of the agricultural livelihoods to climate variability and change differs across agro-ecological systems (AESs). Therefore, the aim of this study was to analyze AES specific vulnerability of smallholder farmers to climate variability and change in the Fincha'a sub-basin. We surveyed 380 respondents from four AESs (Highland, Midland, Wetland, and Lowland) randomly selected. Furthermore, focus group discussion and key informant interviews also performed to supplement and substantiate the quantitative data. Livelihood vulnerability index employed to analyze the levels of smallholders' agriculture vulnerability to climate variability and change. Data on socio-economic and biophysical attribute collected and combined into the indices and vulnerability score calculated for each agro-ecological system. The result revealed that considerable variation observed across the agro-ecological systems in profile, indicator and the three Livelihood vulnerability index-Intergovernmental Panel on Climate Change dimensions (exposure, sensitivity, and adaptive capacity) of vulnerability. The lowland AES exhibited higher exposure, low adaptive capacity, and high vulnerability while the midland AES demonstrated lower exposure, higher adaptive capacity, and lower vulnerability. The wetland and highland AESs scored intermediate results. The result suggests that resilience-building adaptation strategies are vital to reduce the vulnerability of smallholder farmers. The measures taken should consider site-specific agro-ecological system requirements to reduce the vulnerability of smallholder mixed crop-livestock agriculture system. Since the approach based on the long-term realization of the community, any strategy designed based on such assessments is applicable to local condition.

Keywords: Vulnerability Index, Exposure, Sensitivity, Adaptation Capacity, Fincha'a sub-basin

3.1 Introduction

Ethiopia, with a population of 94.4 million (Central Statistical Authority (CSA) 2013) is the second populous country in Africa. The countries economy is principally dependent on rain-fed agriculture; that is largely a “low input and low output” subsistence production system. The overwhelming proportion (95%) of the cropped area and national annual crop production is under smallholder rain-fed farming (EPCC 2015).

Ethiopia frequently cited as a country that is highly vulnerable to climate variability and change (World Bank 2010; Conway and Schipper 2011; EPCC 2015). Historically, Ethiopia is prone to climate-related hazards. Rainfall in Ethiopia is highly erratic; moreover, most rain falls intensively (often as convective storms) with very high variability spatially and temporally. Since the early 1980s, the country has suffered seven major droughts, five of which led to famines in addition to dozens of local droughts (Diao and Pratt 2007).

The nation’s high vulnerability arises first from the heavy dependency of the economy on rain-fed agriculture and the risks associated with rainfall variability. Long-term records indicated repeated rainfall failures resulted in severe chronic food/feed insecurity, including famines due to significant loss of crops and livestock. Second due to the low-level of transfer and adoption of improved agricultural technologies and practices required to meet the production needs of the changing environment. Third, the topographical condition that causes severe land degradation problem coupled with the low adaptive capacity to adverse impacts of climate variability and change are some to mention (Deressa 2006; Byerlee et al. 2007; World Bank 2010; Simane et al. 2014; EPCC 2015).

In Ethiopia, in the last 50 years, the average annual minimum temperature has shown an increasing trend of 0.2^{o}C per decade (EPCC 2015). The nation’s rainfall characterized by seasonal and inter-annual variability (Conway 2000; Seleshi and Zanke 2004). The annual rainfall variability in most part of the country remains above 30% (Kindie et al. 2016). The part of the nation that experiences higher rainfall variability also has relative higher probability of crop failures (World Bank 2006). Evidences suggest that recurrent droughts and the associated food insecurity and famine in Ethiopia are mainly caused by climate, particularly rainfall variability (Conway 2000; Seleshi and Zanke 2004; World Bank 2006; Conway and Schipper

2011; Demeke et al. 2011). In terms of seasonal production the Belg (April to June), season suffers from greater rainfall variability than the Kiremt (July to September) season and most Belg season growing areas (eastern, northeastern and southern part of the country) are suffering from unreliable onset of the season and frequent crop failures (Kindie et al. 2016).

Under climate variability and change, evidences suggest that changes in rainfall pattern causes relocation of suitable area of production for different crops in Ethiopian agriculture. Evangelista et al. (2013) showed that by 2020 the major cereal crops of Ethiopia such as maize, tef, sorghum and barley will loss over 14, 11, 7 and 31% of their current suitable area of production, respectively. On the same token climate variability and change also affects duration of crop growth by slowing or hastening growth and development processes. Kassie et al. (2014) revealed study conducted on maize in the central Rift Valley of Ethiopia using two crop simulation models under various climate change scenarios predicted a reduction of maize growth duration by 14-33 days in 2050 compared to the present due to higher temperature and variable rainfall conditions. Other impact of climate variability and change on crop include the increase in prevalence and dynamics of crop pests and diseases in Ethiopia (Kindie et al. 2016).

Vulnerability means the propensity or predisposition to affect adversely and it encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt (IPCC 2014). There are two main types of vulnerability analysis or approaches exist Outcome vulnerability or End-point vulnerability and Contextual vulnerability or Starting-point vulnerability (Kelly and Adger 2000; O'Brien et al. 2007; Füssel 2007; Nelson et al. 2010). A common string of both is an attempt to quantify multidimensional issues using indicators as proxies.

According to Adger (2006), the challenge of vulnerability research is to develop robust and reliable measures. Even the IPCC definition of vulnerability does not specify any particular assessment methodology or scale of analysis. One functional methodology at household and community levels is the Livelihood Vulnerability Index (LVI) adapted to the IPCC framework (LVI-IPCC) (Hahn et al. 2009; Simane et al. 2014). Under the umbrella of the framework, Hahn et al. (2009) developed an indicator-based vulnerability assessment that has been used by many researchers in different contexts (Pandey and Jha 2012; Shah et al. 2013; Etwire et al. 2013;

Simane et al. 2014; Aryal et al. 2014; Asrat and Simane 2017; Amare and Simane 2017; Chala et al. 2017).

The LVI-IPCC is an execution of the Sustainable Livelihoods Approach to development analysis (Chambers and Conway 1992). According to the approach, the communities described in terms of their natural capital, social capital, financial capital, physical capital, and human capital. It also involves studying how vulnerable a community or the system is as compared to others and the component that pushes up the level of vulnerability within the community (Simane et al. 2014).

Different scholars tried to study the vulnerability of Ethiopian farmers to climate-related extreme events. A research conducted by using panel data sets using a sample of 15 villages Dercon et al. (2005); a research in the Blue Nile Basin (Ethiopia) by Deressa et al. (2008); analysis of rainfall variability and crop production in Amhara Region by Woldeamlak (2009) are a few to mention. The results of most of these studies are very general and aggregated at national levels.

There are also site-specific vulnerability studies conducted in other parts of the country like a research conducted in Dabus watershed (Ethiopia) by Asrat and Simane (2017); Muger sub-basin (Ethiopia) by Amare and Simane (2017); and study conducted in Didesa Basin Southern Part of Abbay Basin (Ethiopia) by Chala et al. (2017) are identified. However, in tropical highlands where the majority of Ethiopian population resides, climatic and biophysical conditions change so dramatically over short distances. Therefore, aggregated national statistics do not capture the complex state of vulnerability at the local level (Simane et al. 2014). Hence, it creates a challenge for policy-relevant implementation of the LVI-IPCC framework in all places of the nation. □

The Blue Nile River basin is one of the most sensitive basins to changing climate and water resources variability in the region (Kim and Kaluarachchi 2009). Specifically, the sub-basin expressed as one of the erosion hot spot and vulnerable areas of the Blue Nile river basin (MoWIE 2014). Therefore, this study conducted to assess the vulnerability levels of all Agro-ecological systems (AES) found in Fincha'a sub-basin by using AES as a unit of analysis. The sub-basin selected for the research because no similar study conducted in the area before. Thus, it is imperative to understand at the local level the nature of climate variability and change vulnerability of smallholder farmers' agriculture. The relevance of AES-based generalization to household-level analysis allows us to map vulnerability profiles across the sub-basin. It is also important for adaptation planning and allows decision makers to understand patterns of vulnerability across relatively broad geographical locations. Although, the study is site specific, the finding obtained from the study provide context-specific contribution to the Agro-ecological system based understanding of the impact of climate variability and change and adaptation responses given as a nation. The subsequent section describes section 2 methodology, section 3 result and discussion, and section 4 conclusions & recommendation.

3.2Methodology

3.2.1 Research Design and Sampling Procedure

The research employed a multi-stage sample design technique to select the Kebeles[2] and households from the most general level (areas having similar Agro-ecological system) to the most precise level (household). In the first stage, the sub-basin divided into similar Agro-ecological systems. Based on the analysis four Agro-ecological systems (Highland, Midland, Wetland, and Lowland) identified in the sub-basin. In the second stage, the seven Districts found in the sub-basin grouped into possible Agro-ecological systems. Then, three representative Districts (Horo, Jima Genete & Hababo Guduru) that represent the four AES selected randomly. Horo District selected to represent the highland and midland agroecosystems, Jima Genete selected to represent the wetland agroecosystm, and Hababo Guduru selected to represent the lowland agroecosystem. The significance was to enable the research to focus on similarity and differences in vulnerability and adaptation strategy, depending on local context and circumstances, to climate variability and change on specific climate zone. Then two Kebles randomly selected from the Districts representing each Agro-ecological system (AES). The number of kebeles was decided based on time and financial constraint.

Finally, a total of 380 mixed crop-livestock farming households, 95 households from each AES, selected by systematic random sampling from eight Kebeles (two from each Agro-ecological system) and participated in the cross-sectional survey. The survey conducted from May to June

[2] The lowest tiers in the administrative structure of the country

2017. The sampling frame (list of households residing in the Kebele) used for selection of households obtained from Kebele administration.

The survey questions designed in such a way to address the eight profiles used in calculating the LVI. They included inquiries on socio-economic and environmental attributes as well as questions related to farmers' perceptions of climate change and adaptation methods. The surveyed farmers also asked questions about their observations regarding patterns of temperature and rainfall over the past 20 years. Household surveys paired with a biophysical survey to assess indicators related to land suitability, conservation practices, and irrigation potential. Focus Group Discussion [FGD] (two from each agroecosystem) and key informant interview [KII] with individual farmers (two from each agroecosystem) also held at the community level in consultation with agricultural experts and development agents working at Keble level. The number of FGD and KII was decided based on time and financial constraint. The data obtained from the FGDs and KIIs used to enhance the survey result. The data from the household survey also triangulated with focus group discussions and field observations data. Another source of information is rainfall and temperature data from 1995 to 2015 from the National Metrological station.

3.2.2 Approaches for Measuring Vulnerability

The integrated assessment approach utilized to determine the vulnerability of Fincha'a sub-basin smallholder farmers to climate variability and change. The approach combines both socio-economic and biophysical approaches to determine vulnerability. The 'hazard-of-place model' (Cutter et al. 2000) and the vulnerability mapping approach (O'Brien et al. 2004) is a good example of this approach, in which both biophysical and socio-economic factors are systematically combined to determine vulnerability.

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

As a methodology, this study adopted the livelihood vulnerability index (LVI) developed and demonstrated by Hahn et al. (2009) in Mozambique. Similarly, different authors used the same framework with some modification to major components to resemble the local context in Ethiopia (Asrat and Simane 2017; Amare and Simane 2017; Chala et al. 2017; Simane et al. 2014). The same methodology employed in this study to assess the vulnerability of smallholder farmers to climate change and variability in Fincha'a sub-basin. The approach defined eight biophysical and socioeconomic profiles related to vulnerability based on review of literatures that match the conditions and constraints facing smallholder agricultural households in the sub-basin. The profiles include climate, ecosystem, agriculture, wealth, technology, infrastructure, community, and social network. Accordingly, the vulnerability index derived for four Agro-ecological systems found in the sub-basin. Each profile is composed of several indicators or sub-components. The eight vulnerability profiles then mapped onto the three IPCC contributing factors to vulnerability. Each of the profiles, with the possible exception of climate profile, can also be associated with one of the five types of capital used in the Sustainable Livelihoods Approach (Chambers and Conway, 1992).

According to IPCC (2007b), to determine the vulnerability of a household or community, vulnerability calculated as a function of exposure, sensitivity and adaptive capacity. The exposure includes the climate variability or change profile including the extreme events. The sensitivity includes the ecosystem and agricultural profiles. The adaptive capacity includes the wealth, technology, infrastructure, community, and social network profiles (Table 3-1). The indicators used to construct the profile for calculating the LVI selected based on primary data generated through a household survey, focus groups discussion, key informant interview, expert opinion, and field observation made in the sub-basin.

3.2.3 Calculating the LVI

The study employed the indicator method for measuring vulnerability. In indicator method, vulnerability quantified based on selecting indicators from the potential set of indicators and then combining them analytically to identify the levels of vulnerability (Hahn et al. 2009). In this study, all indicators of vulnerability assumed to have equal importance and thus giving them equal weights (Cutter et al. 2000). The LVI calculation utilized the approach by Hahn et al. (2009). Different scholars (Mohan & Sinha 2010; Simane et al. 2014; Aryal et al. 2014; Panthi et al. 2015) also used a similar approach in various contexts.

As stipulated by Sullivan et al. (2002), the LVI uses a balanced weighted average approach, where each indicator contributes equally to the overall index even though each major profile is comprised of a different number of indicators or sub-components. The standardization for each index is required because each of the indicators or sub-components measured on a different scale. The formula used for this conversion adopted from the Human Development Index to calculate the life expectancy index, which is the ratio of the difference of the actual life expectancy and a pre-selected minimum, and the range of predetermined maximum and minimum life expectancy (UNDP 2007).

Table 3-1: Vulnerability factors, livelihood capitals, profiles, and indicators used for LVI analysis using the IPCC framework

Vulnerability factors	Livelihood Capitals	Profiles	Indicators	Units	Hypothesized functional relationship
Exposure		1. Climate	• Change in maximum temperature • Change in minimum temperature • Change in precipitation •Climate-related hazards: Drought • Climate-Related Hazards: Flood	Changes over time, °C Changes over time, °C Changes over time, mm No of events over the last 20 years No of events over the last 20 years	Larger change or frequency = higher exposure
Sensitivity	Natural capital	2. Ecosystem	• Land suitability for agriculture • Sustainability of land use system • Land cover change (primarily deforestation/reforestation) • Use of soil water conservation techniques) • Irrigation potential	Avg. scale values of soil depth, terrain, drainage, and fertility of (1–5) The assumed intensity of management (High, Medium and Low) % change over the baseline % of the land with SWC structures Ha of land suitable for irrigation	More forest cover, suitable land, and access to irrigation = lower sensitivity
		3. Agriculture	• Annual total production (inverse) • Changes in productivity • The diversity of crop species	Tons of total product harvested Yield in tons/ha Number of crops in the system	Greater productivity and diversity = lower sensitivity
Adaptive Capacity	Financial Capital	4. Wealth	• Farm size • Number of livestock • Savings at the household level • Existing loans • Non-agricultural income	Ha/HH TLU/HH Amount of Birr (local currency)/HH Amount of Birr/HH Amount of Cash obtained per year	Greater wealth = greater adaptive capacity

Physical Capital	5. Technology	• Insecticide and pesticide supply • Fertilizer supply • Improved seed supply • Irrigation potential	% of HHs using insecticide % of HHs applying fertilizer % of HHs using improved seed % of HHs practicing irrigation	Better access to technology = greater adaptive capacity
	6. Infrastructure	• Access to all-weather roads • Access to schools • Access to veterinary services • Access to markets • Access to savings and credit • Access to electricity • Access to telephone	Walking distance in hours Walking distance in hours Walking distance in hours Walking distance in hours % of HHs using credit % of HHs accessing lights % of HHs using a telephone	Better access to infrastructure = greater adaptive capacity
Human Capital	7. Community	• Sex of household head • Education level • Availability of extension • Skills/training • Health services • Radio ownership	Male/Female % of HH heads No of DAs/village No of training HH head attended Walking distance in hours % of HHs who have a radio	More human capital, information and services = greater adaptive capacity
Social Capital	8. Social	• Governance • Membership in Social Organizations/ CBO • Participation in projects • Availability of bylaws • Number of non-working days/ month • The tradition of working together	1–5 scale (election of leadership) % of HHs who are members of CBO Participation index % of HHs who have bylaws Average number of non-working days in a month % of HH who have a tradition of working together	Fewer non-working days and more tradition of working together = greater adaptive capacity

(Source: Simane et al. (2014), but some indicators and hypothesized functional relationships are customized for this study)

First, each indicator standardized to a common scale:

$$I_v = \frac{I_a - I_{min}}{I_{max} - I_{min}} \quad \text{..} \quad \text{(Eqn. 1)}$$

Where Iv is the standardized value for the indicator, Ia is the value for the indicator I for a particular AESa, Imin is the minimum value for the indicator across all the AESs, and Imax is the maximum value for the indicator across all the AESs. For indicators, which assumed to have an inverse relationship with vulnerability, the inverse scoring technique applied in the standardization of values for each indicator based on ICRISAT (2006).

Inversed Index values (Iv) = (Maximum Value - Observed Values for indicator (Ia) / (Maximum Value - Minimum Value)

Next, a profile average value calculated as:

$$P_a = \frac{\sum I_v}{N} \quad \text{..} \quad \text{(Eqn. 2)}$$

Where Pa is the value for one of the eight major profile in AES a, and N is the number of variables in the profile. Values for each of the eight profiles then combined to obtain the AES level LVI:

$$LVI_a = \frac{\sum_{p=1}^{8} N_p P_a}{\sum_{p=1}^{8} N_p} \quad \text{..} \quad \text{(Eqn. 3)}$$

Where LVIa is the Livelihood Vulnerability Index for AES a, and Np is the number of indicators in each profile.

The eight profiles combined according to the IPCC categorization scheme as:

$$CF_a = \frac{\sum_{p=1}^{f} N_p P_a}{\sum_{p=1}^{f} N_p} \quad \text{..} \quad \text{(Eqn. 4)}$$

Where CFa is an IPCC contributing factor (exposure (E), sensitivity (S), or adaptive capacity (A)), f is the number of profiles associated with the contributing factor, and P_a is the indexed value to the profiles associated with the CF.

Finally, the LVI-IPCC for AESa calculated as:

$$LVI - IPCC_a = (E_a - A_a) * S_a \quad \text{..} \quad \text{(Eqn. 5)}$$

The LVI-IPCC is scaled from −1 (least vulnerable) to 1 (most vulnerable) and is best understood as an estimate of the relative vulnerability of compared populations.

3.3Results and Discussion

The vulnerability analysis results of all the Agro-ecological systems (AESs) presented in two different steps. First, the results obtained from the assessment of individual profiles and indicator's contributions to each of the profiles for each Agro-ecological systems presented together with the overall LVI (Table 3-2, Fig. 3-1). Second, the LVI-IPCC vulnerability estimates done for the Agro-ecological systems based on vulnerability components (exposure, sensitivity, and adaptive capacity) of climate vulnerability index presented (Table 3-6, Fig. 3-2). The LVI provides information of which components determine vulnerability and the LVI-IPCC indicates which of the three factors (exposure, adaptive capacity and sensitivity) influences the most when determining the vulnerability of the AESs. Finally, interaction among vulnerability components (exposure, sensitivity, and adaptive capacity) in each Agro-ecological system (AES) discussed.

3.3.1 Livelihood Vulnerability Index (LVI) Results

Table 3-2 presented indexed indicators, profiles, and overall LVI for highland, midland, wetland, and lowland AESs. The livelihood vulnerability indexes of the eight major profiles also summarized in spider diagram (figure 3-1). In the diagram, the scale goes increasing from the 0.0 or center (less vulnerable) to 0.9 (more vulnerable) for the exposure and sensitivity components profiles and the inverse is true for the adaptive capacity component profiles. The major profiles or components that yield the LVI scores are elements of either of the five capital forms (natural, financial, physical, human, and social) and are grouped into the contributing factors namely exposure, sensitivity and adaptation capacity in order to compute the LVI-IPCC (Table 3-6). Exposure includes the score of the climate profile; sensitivity is composed of two major profiles while adaptive capacity made up of aggregated scores of five major profiles.

Figure 3-1 depicts that Lowland AES scored higher indexed value in climate, ecosystem, and agricultural profiles. In contrast, the lowland AES scored lower values in wealth, technology, infrastructure, community and social profiles. Whereas, the midland AES scored lower indexed values in climate, ecosystem, and agriculture profiles and higher values in wealth, infrastructure, community, and social profiles. These imply that the lowland AES has higher vulnerability factors for exposure and sensitivity components and lower vulnerability factor for adaptive capacity component. While in contrast, the midland AES has lowers vulnerability factors for exposure and sensitivity components and higher vulnerability factor for adaptive capacity component. The highland and wetland AESs scored intermediate results and the details of the major profiles and its associated indicators discussed below.

Table 3-2: Indexed indicators, profiles, and overall LVI for Highland, Midland, Wetland, and Lowland AESs

Profile/ Component	Indicators	Units	Indexed value for each indicator			
			HL	ML	WL	LL
1. Climate	The standard deviation of the average daily maximum temperature by month between 1995 and 2015	Changes over time, °C	0.191	0.182	0.182	0.405
	The standard deviation of the average daily minimum temperature by month between 1995 and 2015	Changes over time, °C	0.148	0.109	0.109	0.391
	The standard deviation of the average monthly precipitation between 1995 and 2015	Changes over time, mm	0.293	0.269	0.269	0.484
	Average number of drought events in the past 20 years	Number of events	0.630	0.149	0.183	1.000
	Average number of flood events in the past 20 years	Number of events	0.359	0.000	1.000	0.755
	Profile Indexed Value		**0.324**	**0.142**	**0.348**	**0.607**
2. Ecosystem	Land suitability for agriculture	Index	0.500	0.000	0.500	0.750
	Sustainability of land use system	Index	1.000	0.000	0.500	0.750
	Land with improved soil water conservation techniques	Percent	0.263	0.221	0.484	0.210
	Irrigation potential	Hectare	0.680	0.830	0.580	1.000
	Profile Indexed Value		**0.611**	**0.263**	**0.516**	**0.678**
3. Agriculture	Average annual total production	Tons per HH	0.652	0.629	0.742	0.682
	Average changes in productivity per hectare	Tons per Ha	0.756	0.754	0.667	0.785
	The diversity of crop species (Inverse)	1/(# of Crops +1)	0.533	0.571	0.571	0.615
	Profile Indexed Value		**0.647**	**0.652**	**0.660**	**0.694**
4. Wealth	Average farm Size of HH	Hectare per HH	0.485	0.480	0.339	0.568
	Average number of livestock per HH	TLU/HH	0.479	0.432	0.347	0.277
	Average Existing loans per HH (Inverse)	Birr/HH	0.713	0.794	0.894	0.467
	Average non-agricultural income	Birr/HH	0.079	0.230	0.010	0.004
	Profile Indexed Value		**0.439**	**0.484**	**0.397**	**0.329**

5. Technology	Households (HHs) who used Insecticide and pesticide	Percent	0.040	0.105	0.088	0.174
	HHs who used Fertilizer	Percent	0.895	0.936	0.915	0.853
	HHs who used Improved seed	Percent	0.596	0.651	0.716	0.642
	HHs who have Irrigation potential	Percent	0.316	0.179	0.421	0.080
	Profile Indexed Value		**0.462**	**0.468**	**0.535**	**0.437**
6. Infrastructure	Average time to access all-weather roads	Hours	0.702	0.761	0.673	0.351
	Average time to access schools	Hours	0.742	0.777	0.742	0.530
	Average time to access veterinary services	Hours	0.731	0.757	0.731	0.574
	Average time to access markets	Hours	0.613	0.747	0.693	0.427
	HHs who have access to savings and credit	Percent	0.653	0.779	0.579	0.200
	HHs who have access to electricity	Percent	0.042	0.137	0.000	0.000
	HHs who have access to telephone	Percent	0.653	0.842	0.337	0.063
	Profile Indexed Value		**0.591**	**0.686**	**0.537**	**0.306**
7. Community	Male-headed households	Percent	0.867	0.960	0.960	0.930
	Household heads attended some level of school	Percent	0.821	0.853	0.632	0.300
	Extension service received	Percent	0.800	0.850	0.870	0.660
	Average number of trainings attended	Number	1.000	1.000	1.000	0.000
	Average time to access health services	Hours	0.514	0.549	0.480	0.411
	Radio ownership	Percent	0.842	0.919	0.558	0.432
	Profile Indexed Value		**0.807**	**0.855**	**0.750**	**0.456**
8. Social	Governance (% of HHs participated in the election of leadership)	Percent	0.870	0.843	0.842	0.789
	Membership in CBOs	% of HHs who are members of CBO	0.895	0.915	0.920	0.821
	Participation in projects	Participation index	0.412	0.618	0.471	0.324
	Availability of bylaws	Percent	0.590	0.680	0.620	0.580
	Average number of non-working days per month	Number of Days	0.558	0.642	0.592	0.125
	HHs who have the tradition of working together	Percent	0.920	0.899	0.798	0.910
	Profile Indexed Value		**0.708**	**0.766**	**0.707**	**0.591**

Where: HL: Highland, ML: Midland, WL: Wetland and LL: Lowland

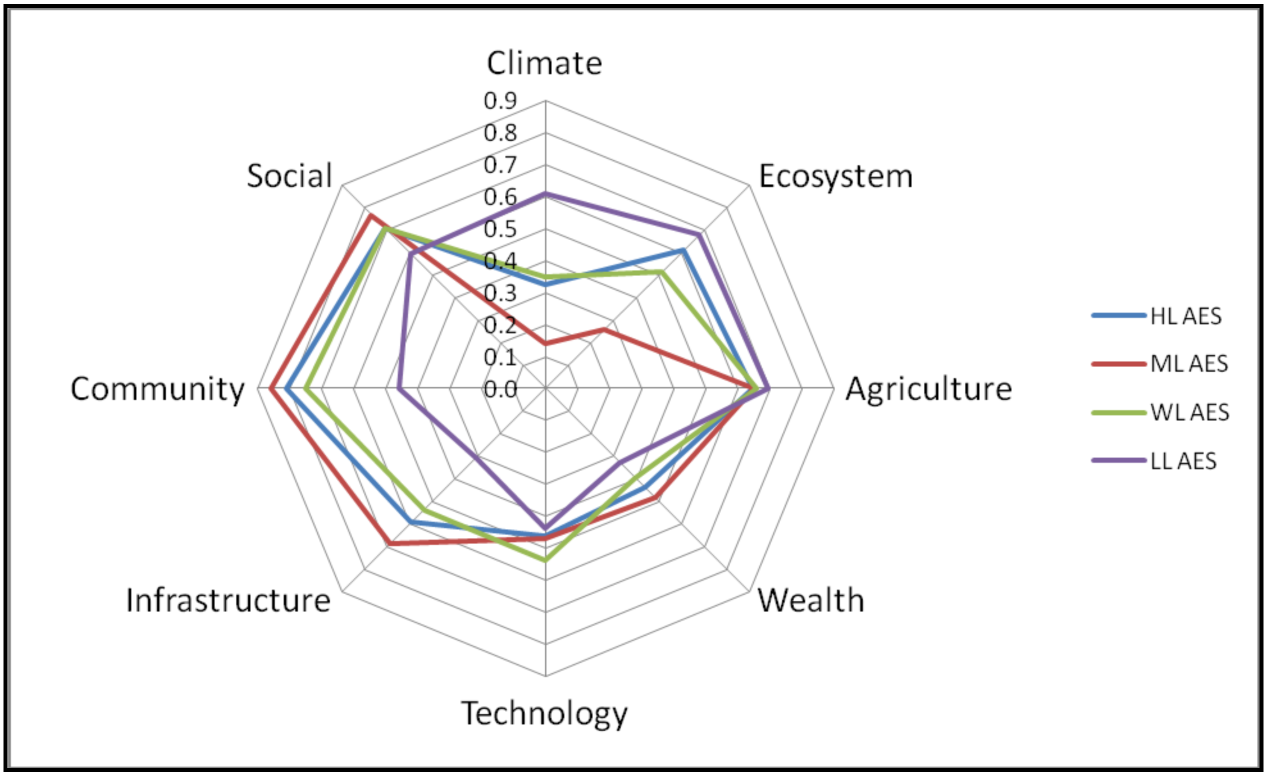


Figure 3-1: Spider Diagram of major Profiles of Livelihood Vulnerability Index (LVI)

Exposure Vulnerability Factor (EVF): Climate profile

This profiles shows what is at risk in view of exposure to climate variability or change. The climate profile includes the climate variability and change, and the natural hazards (weather extreme events) indicators and encompasses five indicators. The analysis of the profile revealed that the lowland AES is more vulnerable by EVF (0.607) whereas the midland AES found to be the least vulnerable by EVF (0.142) (Table 3-2). The wetland and highland AESs scored 0.348 and 0.324 respectively, which is an intermediate result in terms of the profile average value.

The result of the analysis reveals that the lowland AES higher vulnerability arises from the four of the contributing factors. First, the average number of drought events in the past 20 years was the highest for lowland AES (3.58) as compared to 2.81, 1.88, and 1.81 for highland, wetland, and midland AESs respectively. The other weather extreme event that determines the vulnerability of lowland AES is the exposure to flooding. In the past 20 years, the lowland AES exposed to flooding on average 4.52 times as compared to 2.95 and 1.53 for highland and midland AESs respectively. The exposure to flooding event is the highest in wetland AES, which was 5.49 times. Another contributing factor for the higher vulnerability of the lowland AES in climate profile is the average monthly temperature and precipitation change observed in the area as compared to the other agro-ecological systems. In addition to data collected from the national metrological agency, the perception of the community about the change of the different climate parameters collected and 96.8% and 56% of the community responded that there is an increasing trend of temperature and decreasing trend of precipitation respectively in the lowland AES. Generally, by considering farmers' perception and substantiating it with objective metrological record of the past 20 years, the variability in the average maximum monthly temperature and precipitation has been relatively greater in the lowland Agro-ecological system than the corresponding AESs.

Sensitivity Vulnerability Factor (SVF): Ecosystem & Agriculture Profiles

Sensitivity of a system reflects the degree of response to a given change in climate. Thus, the biophysical effects of climate change are broadly groups under the sensitivity component. These include the changes in the natural ecosystem as well as managed systems such as agriculture (Mohan & Sinha 2010). Variations in ecosystem and agricultural profiles together govern the sensitivity levels of Agro-ecological systems.

Ecosystem profile: Land suitability, sustainability of land use system, soil and water conservation practice, and irrigation practices have chosen as the indicators of the ecosystem profile. Based on the calculated indices of the indicators the lowland, highland, wetland and midland AESs scored 0.678, 0.611, 0.516, and 0.263 average profile values respectively. The profile average value revealed that the lowland AES has higher vulnerability score, whereas the midland AES has, lowers vulnerability score. The land suitability for agriculture analysis of these study found that the relative suitability potential of the study sub-basin from highest to the lowest in descending order becomes midland, wetland, highland, and lowland AESs respectively, which is characterized by their relative slopes, productivity of the soils, and the prevailing climatic condition. Suitability is lower in lowland AES, which affected by the low fertility of soils, Landslide, high rate of soil erosion, and rainfall variability. In terms of irrigation potential, the wetland and highland AESs have the highest potential whereas the lowland AES has the least potential.

The highland AES is suffering a lot from severe land degradation problem in the sub-basin. Specifically, in terms of erosion problem, the sub-basin expressed as one of the erosion hot spot areas of the Blue Nile river basin (MoWIE 2014). In the highland AES, the reality is that the steepness of the slope is higher and natural ecosystems have been and being converted to agricultural fields. Consequently, the infiltration and percolation rate of the water to the soil and ground water becomes lower. In contrast, the surface runoff becomes higher; this coupled with increased velocity by the steepness of the slope, and aggravated the problem of soil erosion in this specific AES. The erosion problem is causing onsite productivity reduction by land and nutrient loss and offsite reservoir sedimentation of the hydroelectric dams, and flooding and sedimentation of the agricultural fields of the same AES and wetland AES in the downstream areas.

According to sources from Zonal and District agricultural offices, the problem of land degradation in general and soil erosion in particular are severe. In contrary, measures taken to avert the situation of land degradation were minimal as compared to the required intervention. The result of land with improved soil and water conservation indicator revealed that the relative intervention is higher in highland and lower in the wetland AES. One-way ANOVA analysis reveals that the mean difference among the agroecosystem is statistically significant at ($P < 0.001$) level for land with improved soil and water conservation measures (Table 3-3).

Agricultural Profile: There are three indicators in agricultural profile. The profile indices for the lowland, wetland, midland, and highland AESs are 0.694, 0.660, 0.652, and 0.647 respectively. The vulnerability difference among the agro-ecological systems in this profile is minimal. However, there are differences among the AES in terms of the indicators values. In average annual total production per household indicator, the highest in midland AESs (2.93 tons/HH) and the least is in wetland AES (2.04 tons/HH). The lower amount of production in wetland AES is accounted from the lowest per capita land holding size in this AES. The result of the indicator interpreted as the higher the productivity the lesser the vulnerability.

In terms of average positive changes in productivity per unit area (hectare), the study revealed that the highest is in the wetland (0.32 tons/Ha) whereas the least is in lowland AES (0.21 tons/HH). The highest productivity changes of the wetland AES is accounted from the highest agricultural technology usage of the farmers in the AES. In terms of crop diversity indicator, the highest found in highland and the least found in lowland AES. The result interpreted as the higher the crop diversity the lower the vulnerability. Diversified source of livelihood minimizes the vulnerability of the community to climate variability and change (Turner et al. 2003). One-way ANOVA for household land holding in hectare, average production gained in quintals, and land under irrigation among the Agro-ecological systems is statistically significant at (P < 0.001) (Table 3-3).

Table 3-3: Continuous variables considered in the ANOVA analysis for the four AESs

Variable	F-test	Significance Level
The total hectare of land the household owned	34.258***	0.000
Average production gained at household level in quintals	14.941***	0.000
Hectare of land under irrigation	7.639***	0.000
Size of land with improved soil & water conservation measures in a hectare	12.452***	0.000

***: Significant at 1%.

Adaptive capacity Vulnerability Factor

Adaptive capacity designates the capacity to cope up with the changes and adapt to changing condition. It is dependent on several socio-economic factors such as wealth, agricultural technology usage, infrastructure development, community and social capital profiles (Mohan and Sinha 2010; Simane et al. 2014; Asrat and Simane 2017; Amare and Simane 2017). Each details of the profile and indicators values of the respected Agro-ecological system presented in Table 3-2. The higher adaptive capacity implies the lower the vulnerability of the agroecosystem.

Wealth Profile: The wealth profile is composed of four indicators that include average farm Size of HH, average number of livestock per HH, Average Existing loans per HH (Inverse), and average non-agricultural income. The analysis of the profile revealed that the lowland AES is more vulnerable by profile average value of (0.329) whereas the midland AES found to be the least vulnerable by profile average value of (0.484). The highland and wetland AES scored 0.439 and 0.397 respectively, which is an intermediate result in terms of the profile average value. The higher vulnerability of the lowland AES is presumably accounted from the lower livestock ownership, higher average existing loans per household and minimal average non-agricultural income. According to per capita livestock holding, the highest is in the highland AES (5.57 TLU[3]) and the least is 3.23 TLU in the lowland AES. In line with this, the inverse average livestock unit (TLU) LVI score for indicator is 0.479 for the highland AES and 0.277 for the lowland AES. The result interpreted as the higher per capita livestock holding means the higher adaptive capacity (Table 3-2).

The other indicator in this profile is the average farmland size holding. Farmland size and vulnerability have inverse functional relationship; that is, as farmland size increases vulnerability decreases and vice versa (O'Brien et al. 2004). This is true because it provides an opportunity for crop diversification and implementation of soil conservation measures. Otherwise, vulnerability and adaptive capacity attributed more to utilization and productivity than the absolute land holding (Asrat and Simane 2017). In terms of this indicator, the highest is in lowland (2.13 hectares) and the least in wetland AES (1.27 hectares) which is almost equal to the national average of 1.22 hectares (CSA 2012). However, lowland AES is more vulnerable than the wetland AES. Therefore, this entails that vulnerability may not solely determined by farmland holding size rather by agricultural technological usage, and overall management of the system. In terms of these indicators, the wetland AES is better off than the lowland AES.

The income from non-agricultural (off-farm) activities is the highest in the midland AES and the least in the lowland AES. However, the analysis revealed that the overall non-agricultural income in the sub-basin is minimal. These imply that the farmers' in the sub-basin are more dependent in the agricultural (crop and livestock) income. The larger dependence on agriculture greatly increases household vulnerability since any crop problems like climate variability and change can cause remarkable reductions of income. In terms of average existing loans indicator, the highest is in the lowland AES and the least is in the wetland AES. This indicator has an inverse relationship with adaptive capacity. Owing that the higher the loan a household has the likelihood of its vulnerability increases.

[3] Tropical Livestock Unit (TLU) conversion factor: Camel=1, Cattle=0.7, Horse=0.8, Mule=0.7, Donkey=0.5, Sheep/Goat=0.1, Chicken=0.01 (source: ILCA, 1990)

Technology Profile: The other profile in this vulnerability factor is the technology usage. In this profile, there are four indicators. The technological usages of the farmers determine their level of vulnerability. We assumed as agricultural technology usage increases, productivity proportionally increased and level of vulnerability reduced. There are four indicators in this profile. The profile indices for the wetland, midland, highland, and lowland AESs are 0.535, 0.468, 0.462, and 0.437 respectively. Based on indices value it is clear that the wetland AES is better in terms of adaptive capacity. The higher adaptive capacity of the wetland AES attributes by relative high number of agricultural inputs users.

The higher average changes in productivity per hectare of wetland AES in agriculture profile attributed due to higher usage of agricultural technologies like improved seed and fertilizer application. The least technology usage, which entails lower adaptive capacity and highest vulnerability (0.437) of lowland AES can be associated with low agricultural input usage (fertilizers, improved seeds, pesticides) and almost nil irrigation practice of the surveyed households in this AES. The percentage of farmers who have applied chemical fertilizers across all AESs in the Fincha'a sub-basin is high with an average of about 90% having used chemical fertilizer. However, the total amount of chemical fertilizer applied is low and below the recommended rate, even among farmers that report using some fertilizer.

Generally, according to sources from the Zonal and District agricultural offices and verified during focus group discussion, farmers in the sub-basin have long tradition of using agricultural inputs (fertilizers, improved seeds, pesticides) however; insufficient supply of these inputs is the major problem in the area. Concerning livestock lack of sufficient feed (fodder), low performance of the local breeds, inadequate veterinary service & high prevalence of animal diseases are some of constraining factors that adversely affect livestock productivity in the sub-basin.

Infrastructure profile: Another important factor determines the level of vulnerability of smallholder's farmers residing in the study area. Indicators of infrastructure like access to primary school and access to telephone services in highland and midland AESs are relatively comparable to the national average. Other infrastructures like access to all weather road, marketing, access to veterinary services, and electricity are minimal. Generally, road infrastructure development and electricity access of the sub-basin has many problems.

Out of the total seven indicators included in the infrastructure profile, the analysis for time spent to access to all weather roads, to access schools, to access veterinary services, and to access the input and output market have an inverse functional relationship with vulnerability. That is, as time spent to access services decreases adaptive capacity increases, and vulnerability decreases and vice versa. For example, based on survey result the average time spent to access all weather roads in midland, highland, wetland, and lowland AESs are 0.9, 1.1, 1.2, and 2.3hours respectively. The inversed indexed value for the indicator becomes 0.761, 0.702, 0.673, and 0.351 for midland, highland, wetland, and lowland AESs respectively. Therefore, it is evident that as the time-spent increases adaptive capacity reduces and vice versa for indicator in specific Agro-ecological system. The same procedure followed to determine the indices of access to schools, access to veterinary services, and access to the input and output market indicators of the profile.

In the access to electricity indicator, out of the total surveyed households 86.3% in midland AES, 95.8% in highland AES, and 100% in wetland and lowland AESs have no access to electricity. It is a paradox that the sub-basin is the source of two hydroelectric powers for the nation but suffering a lot from accessing the electricity sources. The highest infrastructure profile value observed in the midland AES (0.686) and the least profile value observed in the lowland AES (0.306). The higher the profile value means the lower the vulnerability and the lower the profile value means the higher the vulnerability. The highland (0.591) and wetland (0.537) AESs scored intermediate results.

One-way ANOVA analysis reveals that there exists a significant difference of time spent to access all-weather roads; time spent to access the nearest schools; time spent to access veterinary service; distance to the nearest input-output market; distance to saving and credit institution; and access to telephone among the four agro-ecological systems (Table 3-4). Generally, insufficient access to infrastructural services persuades vulnerability of smallholder farmers to climate related risks and in effect, it induced inefficient input and output market, low agricultural production, and less adaptive capacity.

Table 3-4: Explanatory Variables considered for ANOVA analysis for the four agro-ecological systems

Variable	F- test	Significance Level
Educational status of the household head in year	39.711***	0.000
Age of the household heads in year	55.358***	0.000
Average number of non-working days per month	175.317***	0.000
Time spent to access all-weather roads	110.234***	0.000
Time spent to access the nearest schools	39.774***	0.000
Time spent to access Health services	7.634***	0.000
Time spent to access veterinary services	10.562***	0.000
Distance to Water Sources	2.263*	0.081
Access to Piped water sources	16.889***	0.000
Time spent to access the nearest input-output market□	64.977***	0.000
Distance to Saving and Credit institution	36.097***	0.000
Access to saving and credit institution whenever required□	29.084***	0.000
Access to electricity	0.9882	0.000
Access to telephone	61.602***	0.000
Access to Radio	25.256***	0.000

*, **, ***: Significant at 10%, 5% and 1% respectively.

Community Profile: the profile has six indicators and the profile indices for the midland, highland, wetland, and lowland AESs are 0.855, 0.807, 0.750, and 0.456 respectively. In this profile, the midland AES has higher adaptive capacity and the lowland AES has lower adaptive capacity. The higher the adaptive capacity means the lower the vulnerability and vice versa. The relative level of school attended by the household head, the number of extension workers available, the climate specific extension service received, the average time spent to access the health facility, and the percentage of households owned radio are the indicators that determine the vulnerability of the lowland AES.

Education and training received believed to have the potential influence on farmers' decision and positively contribute to climate change adaptation. In terms of literacy level, about 85.3%, 82.1%, 63.2% and 30% of the respondents have attended some level of education in midland, highland, wetland, and lowland AES respectively. One-way ANOVA analysis reveals that there exists a significant difference of Educational status of the household head; time spent to access Health services; and ownership of Radio among the four AES (Table 3-4).

Social Profile: The social network is another important profile that determines the vulnerability of the community. Social profile evaluates the social capital like norms, values, and attitudes that predispose people to cooperate; develops trust, reciprocity, and obligation; and establish common rules and sanctions mutually agreed upon it (Cramb & Culasero 2003; Pretty 2003). The social profile component has the highest adaptive capacity scores in midland (0.766) than the lowland (0.591), wetland (0.707), and highland (0.708) AESs. The higher vulnerability of the lowland AES attributed by low level of participation in leadership selection, low level of membership in community based organization, least farming experience, and the highest level of non-working days per month.

Farming experience is one indicator used to determine the social profile value of the Agro-ecological systems. We expected that farming experience provide the opportunity to moderate vulnerability to climate change impacts through adjustments in terms of choosing appropriate crop types and varieties, selection of optimal planting date, practicing relevant cultural and management practices (Gutu et al. 2012). The survey result reveals that farmers' of highland and wetland AESs have 24 years of experience, whereas the midland and lowland AESs have 21 and 19 years of experience respectively. Hence, farmers' of the lowland AES have low chance of making possible adjustments to anticipated impacts of climate variability and change as compared to the other Agro-ecological systems.

Another indicator under the social profile, average non-working days per month, disclose that farmers' of the lowland, highland, midland and wetland AESs have on average 10.5, 5.3, 5.3, and 4.9 non-working days per month. One-way ANOVA analysis reveals that average number of non-working days per month is significant difference ($P < 0.001$) among the four agroecosystems (Table 3-4). The result interpreted as the higher the non-working days, the lower the adaptive capacity and the higher the vulnerability of the community in specific Agro-ecological system.

3.3.2 Livelihood capitals and the relative vulnerability index of AESs

Table 3-5 below presents the vulnerability of the community residing in different Agro-ecological system of the sub-basin from the livelihood perspective. The first livelihood capital is Natural capital that includes the ecosystem and agriculture profiles. In each of the profiles, there are different indicators, which explain the resource availability and its sustainability use. This livelihood capital categorized with sensitivity vulnerability factor and we hypothesized that vulnerability increases with an increase in the sensitivity of the system, as household livelihoods are more at risk from substantial changes in climate. The result revealed that the lowland AES (0.686) is the highest vulnerable where as the midland AES (0.457) is the least vulnerable in terms of Natural capital. The other AESs scored intermediate values.

Table 3-5: Livelihood capitals and relative vulnerability of Agro-ecological systems

Livelihood capitals	Vulnerability factors	LVI Results of AESs			
		HL	ML	WL	LL
1. Natural Capital	Sensitivity	0.629	0.457	0.588	0.686
2. Financial Capital	Adaptive capacity	0.439	0.484	0.397	0.329
3. Physical Capital	Adaptive capacity	0.526	0.577	0.536	0.372
4. Human Capital	Adaptive capacity	0.807	0.855	0.750	0.456
5. Social Capital	Adaptive capacity	0.708	0.766	0.707	0.591

Financial, Physical, Human, and Social livelihood capitals fall under the vulnerability factor of adaptive capacity. In other way, adaptive capacity analysis conducted using access to and control over the livelihood capitals/resources. The financial capital includes the wealth profile (farmland size, number of livestock, non-agricultural income and household loans indicators). We hypothesized as financial capital of a household increased vulnerability decreased. For example, a household who has more livestock could cope with any disaster related to climate variability and change at least for a short period by selling their livestock. In terms of financial capital the lowland AES (0.329) is more vulnerable than the other AESs, whereas the midland AES (0.484) is the least vulnerable.

The other livelihood capital is physical capital that includes the technological and infrastructure profiles. From the livelihood perspective we hypothesized here that the increased availabilities of technologies (like improved seed, fertilizer, and irrigation) and accessibility to different services (like road, school, veterinary services, market, and credit services) reduces vulnerability. The lowland AES with an indexed value of 0.372 is the highest vulnerable and the midland AES (0.577) is the least vulnerable in terms of physical capital.

We identified six indicators of human capital, sex of household head, education, extension services, training attended about available options, time spent to access health services and ownership of radio. From the viewpoint of livelihood, we hypothesized that the male, more educated, household who have access to extension services, informed and more aware, healthy community and who owned radio could adapt more to climate variability and change with available livelihood capitals. In terms of this capitals the midland, highland, wetland, and lowland AESs scored 0.855, 0.807, 0.75 and 0.456 indices respectively. The result revealed that the lowland AES is the highest and the midland AES is the least vulnerable.

The last livelihood capital is the social capital. Another important capital determines the vulnerability of the community within the agro-ecological systems. The social capital of the livelihood capital component has the highest indexed value scores in midland (0.766) than the lowland (0.591), wetland (0.707), and highland (0.708) AESs. The higher indexed social capital value implies the lower vulnerability of the agro-ecological system and vice versa.

3.3.3 LVI-IPCC Vulnerability Estimate

The profile and composite LVI for each AES calculated using the methodology in Equations (1) – (5) and the results produce vulnerability factors measure of exposure, sensitivity, and adaptive capacity and presented in Table 3-6 below. The LVI-IPCC is on a scale from −1 (least vulnerable) to +1 (most vulnerable) and based on the result of the calculation of LVI-IPCC (Eqn. 5), high values of exposure relative to adaptive capacity yield positive vulnerability scores while low values of exposure relative to adaptive capacity yield negative vulnerability scores. The sensitivity factor acts as a multiplier, such that high sensitivity in an AES for which exposure exceeds adaptive capacity will result in a large positive (i.e., high vulnerability) LVI-IPCC score.

Table 3-6: Calculated indices for contributing factors and the Livelihood Vulnerability Index under the LVI-IPCC framework

AES	Exposure	Sensitivity	Adaptive Capacity	LVI- IPCC
Highland	0.324	0.626	0.623	-0.187
Midland	0.142	0.429	0.679	-0.231
Wetland	0.348	0.578	0.601	-0.146
Lowland	0.607	0.685	0.426	0.124

The LVI-IPCC analysis yielded -0.231, -0.187, -0.146 and 0.124 results for Midland, Highland, Wetland, and Lowland AESs respectively (Table 3-6). According to this result, the relative exposure is high (0.607) and adaptive capacity is low (0.426) for Lowland AES. This results in positive LVI-IPCC scores, which we classify here as "highly vulnerable" since it indicates an adaptation capacity deficit and high exposure relative to other AESs. On the contrary, exposure is low (0.142) and adaptive capacity is high (0.679) for Midland AES that shows the overall vulnerability is estimated to be low. The Wetland and Highland AESs exhibit intermediate vulnerability value. The result reveals the variation in the level of exposure, sensitivity and adaptive capacity of smallholders mixed crop and livestock farmers across Agro-ecological systems in the Fincha'a sub-basin.

The livelihood vulnerability indexes of the eight major profiles also summarized in spider diagram (figure 3-1). The spider diagram yielded similar results. In the diagram, the lowland AES scored higher value in almost all exposure and sensitivity components profiles and lower values in adaptive capacity component profiles. Similarly, vulnerability triangle (Figure 3-2) depicted the contributing factor scores for exposure, adaptive capacity, and sensitivity. The triangle illustrates that the lowland AES scored higher value in exposure and sensitivity components and lower value in the adaptive capacity component. The higher exposure and sensitivity value as compared to adaptive capacity is an indication of higher level of relative vulnerability. In contrast, the midland AES scored the least exposure and sensitivity value and the highest adaptive capacity value as compared to other AESs, which is an indication of the relative low vulnerability of the midland AES to climate variability and change impacts.

In general, the climate, ecosystem, wealth and infrastructure profiles are strong determinants of vulnerability. The social and community profiles were other determinants that played an intermediate role with fewer differences amongst the different agro-ecological systems. The agriculture and technology usage profiles were not major factors as there were few significant differences amongst the AESs.

In terms of geographic area of the sub-basin, the midland AES accounts the largest (44.7%), whereas the highland, lowland, and wetland AESs accounts 21.9%, 18.4% and 15% of the total land area respectively. These further explained that 44.7% of the sub-basin with rolling plateau and brown to red soils has a relatively low vulnerability to climate variability and change. The estimated LVI-IPCC index further suggests that 18.4% land area of the lowland with warm semiarid AES of the sub-basin categorized as having the highest relative vulnerability.

The mountainous highland with sloping terrain AES and the wetland with artificial lakes AES (covering a land area of 36.9%) have a moderate vulnerability value. If not properly managed with the proper adaptation strategies, the mountainous highland AES can be easily vulnerable due to high risk of land degradation problem verified during focus group discussion and sources from Zonal and District agriculture and natural resource offices. Land degradation problems expected to increase with changing climate and associated extreme weather events coupled with change in land use system. In the highland AES, land degradation in general and soil erosion specifically is a phenomenon that endangers the livelihoods of rural farmers' ability to produce crops and livestock. The wetland AES and the artificial lakes constructed for the generation of hydroelectric power also suffering a lot from the problem of siltation that arises from the highland AES and associated midland AES.

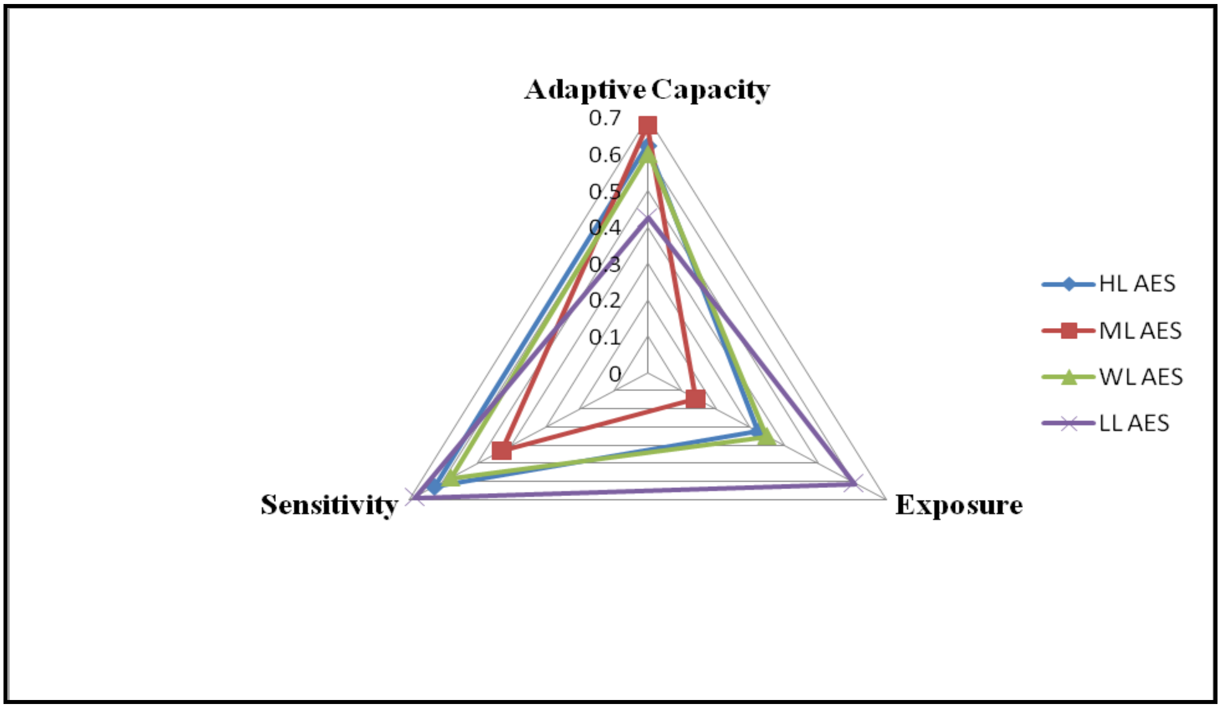


Figure 3-2: Vulnerability Triangle Diagram of the dimensions of Climate Vulnerability Index (CVI)

3.4Conclusion and Policy implications

The finding of this study discloses the general as well as Agro-ecological system (AES) specific factors contributing to different components of the vulnerability of the IPCC that includes exposure, sensitivity and adaptive capacity for mixed crop-livestock smallholders' households. The comparison across AESs helps to identify Agro-ecological system specific adaptation strategies.

The result revealed that in Fincha'a sub-basin, exposure is high and adaptive capacity is low for Lowland AES. This results in minimum LVI-IPCC scores, which we classify here as "highly vulnerable" since it indicates an adaptation capacity deficit and high exposure relative to other AESs. The opposite is true for midland AES, in which adaptive capacity exceeds exposure and overall vulnerability estimated to be low. The highland and wetland AESs exhibit intermediate vulnerability scores. Generally, there was a small difference in the estimated LVI-IPCC score value for the four Agro-ecological systems.

The indexed values for each profile and indicators varied evidently across AESs, which provided insight into the design and implementation of AES specific adaptation strategies for smallholders farmers' of the sub-basin. Among the four agro-ecological systems, the lowland AES requires implementing appropriate adaptation strategies like conservation agriculture that provides a viable means for strengthening resilience in agro-ecological systems and livelihoods that advance adaptation goals (IPCC 2014). Particularly, the highland AES requires massive soil and water conservation intervention to reduce the vulnerability otherwise the highland and wetland AESs and the benefit of hydroelectric dams constructed by the government will jeopardize.

Generally, to ensure sustainable agricultural production and to minimize the livelihood vulnerability of the community to climate variability and change, it is advisable to enhance the supply of agricultural technologies (improved seed varieties, fertilizer supply and irrigation development) that is a bottleneck in the sub-basin. In addition, enhancing community-based participatory watershed management approach based on local knowledge and practices is other area that requires due consideration.

Finally, this study suggests that Agro-ecological system based vulnerability assessment of a sub-basin or landscape level study to climate variability and change, and comparison across Agro-ecological systems help to identify AES specific adaptation strategies. The approach based on the long-term realization of the community residing in the area. Therefore, any strategy designed based on such assessments is applicable to local condition. Moreover, the assessment relates several features of socio-economic and biophysical attributes of the communities.

4. SMALLHOLDER FARMERS' PERCEPTION & ADAPTATION TO CLIMATE VARIABILITY & CHANGE

ABSTRACT

Climate variability and change make agricultural sector a risky enterprise for smallholders' farmers'. This paper presents an assessment of smallholder farmers' perceptions of climate variability and change, associated impacts on agricultural sector and the adaptive responses given in Fincha sub-basin of Blue Nile River Basin of Ethiopia. We interviewed 380 head of households selected through systematic random sampling from eight Kebeles, two each from highland, midland, wetland, and lowland agroecosystems. Furthermore, focus group discussion and key informant interviews also performed to supplement and substantiate the quantitative data. Descriptive statistics and $\chi 2$ tests used to summarize quantitative data. The result revealed 94% of the farmers perceived an increase in average temperatures, 88% perceived a decrease in total average annual rainfall, and about 89% believed, there is overall change in seasonality of rainfall over the last 20 years. The majority of farmers also perceived the frequency and severity of extreme weather events (drought and flood) increased during the same period. The main impact on agriculture as reported by respondents include decline in length of growing period, the decreased and variability of water availability, increased crop damage by insects and pests, increased infestation of weeds, and increased incidence of livestock disease. The adaptive responses given by farmers to perceived change include modification in crop and livestock production practices, and investment in land and water management activities at household and community level. The study also revealed the presence of multiple barriers that hindered the adoption of adaptation measures. The result of the analysis of adaptation measures shows the adoptions of the measures are below average. The adaptation measures implemented until now are not adequate to meet the impending challenges situate by climate variability and change. There is also extrication between farmers' perceptions of climate variability and change, and actual adaptation level. Despite significant number of farmers' perceived changes in temperature (about 93%) and rainfall (about 88%), the number of farmers adopted certain adaptation measures are below average. These necessitate the need for planned interventions to identify and support effective adaptation measures.

Keywords: Climate Change, Perception, Adaptation, Adaptation Barriers, Fincha sub-basin

4.1 Introduction

Climate variability and change coupled with substantial threats for society and nature. To reduce these threats, adaptation and mitigation are the two possible societal response options (Füssel 2007; IPCC 2014). In the climate change context, adaptation is the process of adjustment to actual or expected climate and its effects in order to either lessen or avoid harm or exploit beneficial opportunities and mitigation is the process of reducing emissions or enhancing sinks of greenhouse gases (IPCC 2014). The two possible options (mitigation & adaptation) cannot substitute with each other rather complementary to each other (Füssel 2007; IPCC 2014). The already surfaced impact of climate change possibly addressed only through adaptation because it is difficult to reverse the already changed climate condition by mitigation. However, mitigation activity undertaken now has a reduction power in the long-term requirement of adaptation. Undoubtedly, climate change could impair economic growth of the nations and other facets of societal and natural wellbeing if the required adaptive measures not well taken now (Chambwera & Stage 2010; IPCC 2014; Ethiopian Panel of Climate Change [EPCC] 2015).

Historically, farmers have always attempted to adapt to the changing environmental condition of the agricultural systems. The attempt of the farmers to adapt becomes sometime successful and other time vain. Therefore, adaptation to changing climate condition by farmers has been the norm rather than the exception (Adger 2003; Füssel 2007; Lotze-Campen & Schellnhuber 2009; Below et al. 2010; EPCC 2015). However, the current speed of climate change is inducing and modifying known variability patterns beyond the coping capacity of systems (FAO 2008). As a prerequisite for adaptation, awareness by society about the changing condition of the climate required (Tripathi & Mishra 2016). Different scholars argued the importance of knowing the perception of the local people about the changing condition of the climate to facilitate the adaptation process (Woldeamlak & Dawit 2011; Woldeamlak 2012; Tiwari et al. 2014; Nega et al. 2015). Perceptions of climate change may affect how people will respond and adapt to its multiple impacts (Woldeamlak 2012).

Studies of agricultural adaptation carried-out at two broad scales: macro- and micro-levels (Kandlikar & Risbey 2000). At macro-level, it deals with adjustments of agricultural production systems at national and regional levels, and at micro-level, it is concerned with adjustments and decision making at farm level (Risbey et al. 1999; Kandlikar & Risbey 2000; Kurukulasuriya & Rosenthal 2003; Nhemachena & Hassan 2007). By taking time of response as a measure category adaptation might be proactive (refers to an adaptation that takes place to anticipatory climate stimuli) or reactive (refers to an adaptation that takes place in response to already observed climate stimuli) (IPCC 2007b). Based on forms, adaptation can be either autonomous (private/collective) and/or planned (public sector) adaptation (Füssel 2007; EPCC 2015).

Ethiopian economy is typically driven by agricultural sector despite the issue of high rainfall variability that leads to frequent drought, severe land degradation (especially in the highland region), and poor land management practices (Diao & Pratt 2007; World Bank 2010; Conway & Schipper 2011; EPCC 2015). The sector contributes about 38.5% of the Gross Domestic Product (GDP), 85% of the employment, 90% of the export earnings, and 80.2% of the populations' earnings coming from this sector. It is also the major source of food for the population and hence the prime contributing sector to food security (World Bank 2008; MoFED 2010; Central Statistical Agency [CSA] 2013; National Planning Commission 2016).

According to the National Adaptation Program of Action (NAPA), the foremost-predicted impacts of climate change on Ethiopia's agriculture include dry spells and frequent droughts, reduced growing season, and increased occurrence of pests and diseases (National Metrological Agency [NMA] 2007). The same report also identifies drought and floods are the two major weather extreme events in future climate of Ethiopia, and agriculture and food security are the sectors impacted most. Ethiopia frequently cited as a country that is highly vulnerable to climate variability and change. A major underlying vulnerability factor is the heavy dependence of the economy on climate sensitive rain-fed agriculture system (World Bank 2010; Conway & Schipper 2011; EPCC 2015; Arragaw & Woldeamlak 2016; Paul & Weinthal 2018).

Studies have shown that smallholder farmers in different parts of Ethiopia are facing different climate variability and change related problems. Such problems include reduced or variable rainfall, warming of temperatures, change in length of growing seasons, crop and livestock pests and diseases, weed problems, flooding, shortage of water and land degradation (Woldeamlak 2012; Wagesho et al. 2013; Arragaw & Woldeamlak 2017). The impact of climate variability and change contributes to reduced agricultural productivity, and without sound adaptation strategies by farmers, jeopardized the future sustainability of the sector in the area (Arragaw & Woldeamlak 2016).

To overcome the problem of climate variability and change, reported adaptation measures practiced by smallholder farmers of Ethiopia include crop/livestock diversification, soil and water conservation, planting trees, changing planting dates, and irrigation (Deressa et al. 2009; Amdu 2010; Woldeamlak & Dawit 2011; Woldeamlak 2012; Gebrehiwot & van der Veen 2013; Tessema et al. 2013). Similarly, the most frequently cited barrier to adaptation include lack of information on adaptation options, land shortage, money shortage, labor shortage, lack of access to fertilizer, insecure land tenure, poor market access and poor potential for irrigation (Deressa et al. 2009; Amdu 2010; Gebrehiwot and van der Veen 2013; Tessema et al. 2013).

This study aim to comprehend the agroecosystem based climate change perception, the impact of the change on crop & livestock production, the adaptive responses and barriers to adaptation of smallholder farmers in the Fincha sub-basin. The rationale behind for mapping agroecosystem as a unit of analysis is because AES is an intersection of a set of agriculturally relevant climatic factors; soils and physiographic variables relevant to crop production; and a prevailing set of cropping practices. The specific objectives were to (i) examine the perception of smallholder farmers' and the impact of climate variability and change on agriculture, (ii) describe the adaptive response of farmers' to climate variability and change, and (iii) identify the major barriers for adoption of adaptation measures. The sub-basin selected for the research because no similar study conducted in the area before. Thus, it is imperative to understand at the local level the nature of climate change impact on agriculture, the vulnerability of the sector, and adaptive response given by the local community. Although, the study is site specific, the finding obtained from the study provide context-specific contribution to the agroecosystem based understanding of the impact of climate variability and change and adaptation responses given as a nation. The subsequent section describes section 2 methodology, section 3 result and discussion, and section 4 conclusions & recommendation.

4.2Methodology

Data Collection and Method of Analysis

The study employed a multi-stage sampling procedure to select the District, Kebeles[4] and households from the most general level (areas having similar agroecosystem) to the most precise level (household). In the first stage, the sub basin divided into similar agroecosystems based on the overlay of three inputs: an agro-climatic zoning based on precipitation and temperature, a soil and terrain analysis, and a map of the distribution of farming systems (Table 2-3). Based on the analysis four agroecosystems (Highland, Midland, Wetland & Lowland) identified in the sub-basin (Figure 2-4). In the second stage, the seven Districts found in the sub basin grouped into possible agroecosystems and three representative Districts (Horo, Jima Genete & Hababo Guduru) that represent the four agroecosystems selected randomly. The significance was to enable the research to focus on similarity and differences in vulnerability and adaptation strategy, depend on local context and circumstances, to climate variability and change on specific agroecosystem. Then, two kebeles selected randomly for each agroecosystem from the selected Districts. A systematic random sampling method employed for the selection of respondent household heads. The sampling frame (list of households residing in the Kebele) used for selection of households obtained from kebele administration.

Finally, 380 randomly sampled households selected living in eight Kebeles (two Kebeles in each AES), 95 households from each agroecosystem, participated in cross sectional survey. The detailed survey questionnaire generated household level data on household socio-demographic characteristics, perceptions of climate change, perceived impacts of climate change on agricultural production, adaptive responses employed and barriers to implement adaptation measures to current climate variability and change. To augment the quantitative information obtained from household survey, focus group discussions [FGD] (two from each agroecosystem) and key informant interviews [KII] with individual farmers (four from each agroecosystem) undertaken by using semi-structured checklists to generate additional in-depth qualitative information. The timeframe considered to assess climate change perceptions was the past two decades. The fieldwork carried out from May to June 2017.

[4] The lowest tiers in the administrative structure of the country

To analyze the data descriptive statistical method that comprises percentages, means and frequencies employed to summarize quantitative data on climate variability and change perceptions, impacts, adaptation strategies, and barriers to adaptation. Chi-square test (χ^2) also used to test the statistical significance of variations across the four agroecosystems. Qualitative data used to augment and substantiate the quantitative analyses. The statistical software packages SPSS (statistical package for social scientists) and MS EXCEL used for data management and analysis.

Composite Index of Adoption (CIA) developed by Barungi & Maonga (2011) used to know the intensity of adoption of adaptation strategies. These help to understand the variation in utilizing technologies and for effective formulation of adaptation strategies. CIA computed as follows

$$\text{CIA} = \frac{\sum_{t=1}^{t=n}\left(\frac{T_a}{T}\right)}{N}$$

Where Ta denotes the total number of coping or adaptation strategies used by a farmer; T denotes the total number of coping or adaptation strategies available; N denotes the sample size and Ta/T/N represents the index of adoption for a household.

4.3Results and discussion

4.3.1 Farmers' Perceptions of Local Climate Variability & Change and its Impacts

4.3.1.1 Demographic Characteristics of the Respondents

Table 4-3 below presents the demographic characteristics of sampled households in terms of gender, age composition, marital status, education level, religion, and ethnic background. Out of the total 380 people participated in the study 353 (92.9 %) were male and 27 (7.1 %) were female. In terms of age category, the majority of respondents (68.4 %) are within the active working age group (31–65), while 28.7 % are between the age of (15 – 30) and the rest (2.9 %) respondents are above 65 years of age. 348 (91.6 %) respondents were married and the remainder (4.2%, 3.15% & 1.05%) were single, widowed & divorced respectively. When we evaluate the Education level of the respondents (37.1 %) are illiterate, (37.9 %) are able to read and write, while the rest (25 %) completed either primary education (1–4 years schooling) or secondary school and above. Orthodox and Protestant are the dominant religions of the respondents having (54.7%) & (36.7%) respectively. Ethnically, 96.6% of the respondents are Oromos.

Table 4-1: Characteristics of the respondants (n=380)

Characteristics	Category	%
Gender	Male Headed Households	92.9
	Female Headed Households	7.1
Age	15 - 30	28.7
	31 - 65	68.4
	>65	2.9
Marital status	Single	4.2
	Married	91.6
	Divorced	1.05
	Widowed	3.15
Education	Illiterate	37.1
	Reading & Writing	37.9
	Primary School	16.6
	Secondary School & above	8.4
Religion	Orthodox	54.7
	Protestant	36.8
	Wakefetta	7.4
	Muslims	0.8
	Catholic	0.3
Ethnic Background	Oromo	96.6
	Amhara	3.4

Source: Field Survey, 2017

4.3.1.2 Farmers' Perceptions of Local Climate Variability and Change

Of the different climatic change parameters, respondents asked about their observations of local changes in temperature, precipitation, and climatic extreme events (drought & flooding) over the past two decades. In terms of temperature changes, about 92.9 % (standard deviation of 6.6% among agroecosystems) of the total respondents perceived that the temperature has increased over the last 20 years with significant difference among households in the four agroecosystems. In terms of total annual rainfall 87.9% (standard deviation of 11.5% among agroecosystems) of the total respondents perceived that, the total annual rainfall has decreased over the last 20 years with significantly different at 1% level of significance across agroecosystems. About 88.7% believed that there is overall change in seasonality of rainfall; 85.6% experience drought extreme weather event; and 87.9% experience flooding extreme weather events in the past 20 years (Table 4-2). Findings from focus group discussions and key informant interview also substantiate the information from survey results.

Farmers' perception of increased temperature is consistent with what reported in the National Adaptation Plan of Action and Ethiopian Panel of Climate Change (EPCC) that the average temperature in the country increased for the last five decades. Conversely, the perceived decline in rainfall does not show decreasing records in many parts of the country rather show variability (NMA 2007; EPCC 2015). KIIs & FGDs unanimously witnessed increasing trends of temperature. Regarding rainfall, the discussants raised different views: all participants agreed the change in rainfall pattern but there are diverse views among the participants in overall amount of rainfall. Some argued total annual amount increased and many others said decreased. The difference is mostly associated with the variation in agroecosystem. Similar finding of farmers' perception of increased temperature and decreased rainfall reported by earlier studies conducted in other parts of the country (Deressa et al. 2008; Aklilu & Alebachew 2009; Woldeamlak & Dawit 2011; Woldeamlak 2012; Getachew et al. 2018).

Assuming the negative sign of regression analysis in the trend of precipitation of the Fincha'a and Shambu weather stations strengthens the subjective assessment of the households (figure 1-4 & 1-5). Whereas, the trend of precipitation of Neshe and Homi weather stations shows a positive sign and negate the subjective assessment of the households (figure 1-6 & 1-7). The difference might be because of farmers assess precipitation not merely based on the amount but also consider its uniformity, intensity and pattern over time and space. With regard to maximum and minimum temperature, the sign of regression analysis of the three stations show an increasing trend with the exception of maximum temperature at Neshe, where it shows a declining trend (figure 1-4 to 1-6). However, with the exception of Neshe weather station minimum temperature, the variations in both parameters are not statistically significant.

A study that covered 90 households in three rural kebeles of Menz Mama Midir District in the Amhara National Regional State of Ethiopia reported a similar finding. All of the respondents perceived increase in temperature and decrease in annual rainfall (Woldeamlak 2012). Likewise, a study that covered (n=500) households in five sample Districts in two river basins (Abbay and Baro-Akobo) of Ethiopia reported a similar finding. A majority of respondents perceived increase in temperature (82% of total respondents) and decrease in annual rainfall (96% of total) (Woldeamlak & Dawit 2011). A study that was conducted in the southern lowlands of Ethiopia also found that 93% and 88% of respondents (n = 359) perceived increase in mean temperatures and decrease in annual rainfall respectively (Aklilu & Alebachew 2009). Similarly, previous study undertaken by Deressa et al. (2009) in the Nile Basin of Ethiopia that covered (n=1000) households also reported that a majority of respondents perceived that there was an increase in temperature and decrease in annual and seasonal rainfalls. Finally, they concluded that majority of the respondents covered by their survey (n = 1000) in the Nile basin of Ethiopia were aware of climate change.

Table 4-2: Farmers' perceptions of local climate variability and change (% of respondents)

Climate change factors	Agroecosystems of the sub basin				Total	χ^2-value
	Highland	Midland	Wetland	Lowland		
Temperature						
Increasing	85.3	89.5	97.9	98.9	92.9	23.67**
Decreasing	8.4	4.2	1.1	0	3.4	
No change	3.2	1.1	0	0	1.1	
I don't know	3.2	5.3	1.1	1.1	2.6	
Precipitation (Total Annual)						
Increasing	21.1	5.3	10.5	0	35	36.06***
Decreasing	72.6	91.6	87.4	100	87.9	
No change	6.3	3.2	2.1	0	2.9	
Change in seasonality	82.1	89.5	85.3	97.9	88.7	13.29***
Extreme events						
Experience of extreme weather event (drought) in the past 20 years	76.8	94.7	77.9	93.7	85.6	22.2***
How frequent does drought occur in the past 20 years?	2.81	1.5	1.88	3.58	2.4	
Experience of extreme weather event (flood) in the past 20 years	76.8	91.6	91.6	91.6	87.9	14.6***
How frequent does flood occur in the past 20 years?	2.95	1.53	5.49	3.02	3.3	

Note: *** indicates significance at 0.01, and ** at 0.05probability levels.

Studies conducted in other parts of Africa have also shown a similar trend of an increase in temperature and decrease in precipitation of the climate change parameters. For instance, studies conducted in 10 sub-Saharan African countries by World Bank on perceptions of an adaptation to climate change that covered over 9500 smallholder farmers found that significant numbers of farmers across 10 countries believed average temperatures had increased (Maddison 2007). Similarly, study conducted in different parts of Kenya (n=710) reported that 94% of the farmers perceived an increase in average temperatures and 88% perceived a decrease in average rainfall over the last 20 years (Bryan et al. 2011).

Generally, the people's perception of increased temperatures is consistent and shows similar result with meteorological records in many parts of the country (NMA 2007; EPCC 2015). According to the respondents, the frequency and severity of extreme weather events (drought and flood) increased in the study sub-basin. Over the past 20 years, on average each study households experience 2.4 times drought and 3.3times flooding. Similar finding reported by Mahoo et al. (2013) which states the frequency and severity of natural shocks has increased in recent years in Ethiopia.

Box 1. Elderly key informant from Gitilo Najor Kebele (highland agroecosystem) about the perceived climatic and other changes

Mr File is a 61-year-old farmer (male) in highland agroecosystem. He has lived in the area all his life and is currently head of a family of seven household members. Over the past 20 to 30 years, he reported that he had observed the following climatic and related changes:

- Rainfall variability increased over the past years. Shift in the seasonal rainfall pattern, especially sudden interruption of rainfall by the end of the rainy season is a common phenomenon.
- Temperatures are increasing year by year, and in consequence crops like tef (Eragrostis abyssinica), noug (Guizotia abyssinica) and even maize (Zea mays) at the periphery that were not grown in the highland agroecosystem have now started growing.
- The incidence of disease and pest frequency increased, and consequently our crop production and productivity level affected highly.
- The number of people in the area is increasing and the per capita land holding of the farmers decreasing from time to time.

4.3.1.3 Farmers' Perceptions of Climate Variability & Change Impact on Agriculture

Climate variability and change affects crop and livestock production in many ways. Particularly, crop production affected mainly by changes in temperature, rainfall, which collectively influence the length of growing period, time of critical growth rate, increased evapo-transpiration and hence seriously reduced and in some cases causes complete crop failure (Mahoo et al., 2013). Table 4-5 presents respondents' observation of climate variability and change impact on crop and livestock production in the study sub-basin. Though there are variations among AES, more than 85% of farmers had observed decline in length of growing period during the main Kiremt season. The finding is compatible with Paul et al. (2013) who stated climate change scenarios and models suggest that many parts of Ethiopia are likely to experience a decrease in the length of growing period, and even the decrease is severe in some areas. Any change in the crop-growing period is a challenge as it considerably affects farmers' decisions on what and when to plant (Woldeamlak 2012). With statistically significant differences among the AES, about 41.6% of total respondents reported decline in water availability, while 39% believed that there was more variability in water availability (Table 4-3).

Table 4-3: Perceived impact of climate variability & change on agriculture (percentage of respondents)

Indicator	Response	Agroecosystems of the sub-basin				Total	χ^2-value
		Highland	Midland	Wetland	Lowland		
Change in length of growing period	Increase	0	0	0	1.05	0.26	79.92***
	Decrease	93.7	96.8	92.6	56.9	85.00	
	No change	6.3	3.2	7.4	42.1	14.7	
Change in water availability	Increase	6.3	0	28.4	0	8.7	159.65***
	Decrease	18.9	52.6	29.5	65.3	41.6	
	More variable	40.0	43.2	37.9	34.7	38.9	
	No change	34.7	4.2	4.2	0	10.8	
Change in crop disease	Increase	65.26	82.1	83.16	85.26	78.95	14.56**
	Decrease	0	0	0	0	0	
	No change	34.74	17.9	16.84	14.74	21.05	
Change in crop damage by insects and pests	Increase	82.1	100	91.58	100	93.42	33.69***
	Decrease	0	0	0	0	0	
	No change	17.9	0	8.42	0	6.58	
Change in the problem of weeds	Increase	89.47	100	92.63	100	95.52	25.18***
	Decrease	0	0	2.11	0	0.53	
	No change	10.53	0	5.26	0	3.95	
Any shift in suitable growing areas	Yes	100	76.84	80.0	0	64.21	240.3***
	No	0	23.16	20.0	100	35.79	
Change in livestock disease	Increase	42.11	78.95	69.47	82.11	68.16	43.38***
	Decrease	0	0	0	0	0	
	No change	57.89	21.05	30.53	17.89	31.84	

Note: *** indicates significance at 0.01, ** at 0.05, and * at 0.10 probability levels.

Similarly, about 79% of respondents observed an increased incidence of crop damaged by disease, 93% respondents observed an increase incidence of crop damage by insects and pests, and 96% respondents observed the severity of weed infestation in crop fields as one of the manifestations of climate variability and change. As farmers confirmed during focus group discussion and key informant interview, through, the problems of agricultural crop diseases, insects, pests, and weeds are an already existing problem in the study area, it is aggravated and increased in incidence over the past 20 years in the study sub-basin. With a statistically significant difference among the AES, about 68% of respondents reported an increase in the incidence of livestock diseases and the rest (32%) observed no change in the occurrence of livestock diseases. During focus group discussion, shortage of livestock-feed raised as one major problem and farmers agreed, as the problem is shortage of grazing land rather than climate change.

The perception of the farmers residing in different AES, which is the reflections of local impacts, can vary with variations in agroecosystem conditions. A higher proportion of households in highland, midland, and wetland AES areas perceived changes in length of crop growing period as compared to the lowland AES. Change in water availability is higher in lowland AES as compared to the other AES being the difference is statistically significant. The incidence of agricultural pests, diseases, and weeds are comparable being the difference is statistically significant. The shift in crop growing areas is higher in highland, midland, and wetland AES as compared to households in lowland AES, the difference being statistically significant. The incidence of livestock disease increased in lowland, midland, and wetland AES as compared to the highland AES. The result supports scientific predictions and evidence elsewhere that climate change impacts are more likely felt visibly in the climatically extreme areas (cold highland and dry lowland areas) compared to those in intermediate conditions. Generally, there was a statistically significant difference in the different indicators of climate change perceptions across the four AES (Table 4-3).

4.3.2 Farmers' adaptive responses to climate variability and change

The adaptive responses of the farmers' to the perceived climate variability and change categorized into two broad categories of adjustments in crop and livestock production, and responses through natural resources management.

4.3.2.1 Adaptive responses in crop and livestock production

In the study area, where the total annual average precipitation volumes are relatively higher (about 1650 mm), as farmers verified the greatest impacts on agricultural production are from changes in rainfall variability, such as prolonged periods of drought and changes in the seasonal pattern of rainfall. Table 4-4 presents the adaptation measures implemented by smallholder farmers to overcome the challenges of climate variability and change in crop and livestock production in the sub-basin. The adaptation measures implemented in crop production includes: i) using new crop varieties (50.8% of the total respondents), ii) incorporation of crop residue (37.6% of the respondents), iii) adjusting the agricultural calendar/ dates of planting and harvesting (32.9% of the respondents) and iv) use of early maturing crop varieties for the crops traditionally produced (26.6% of the respondents). Despite the number of adaptors are relatively small, practices such as increased diversification of crops produced (25.8% of the total respondents), use of drought tolerant crop varieties (20.5% of the respondents), use of disease/pest tolerant crop varieties (4.5% of the respondents), and planting high value fruit trees (1.6% of respondents) had been practiced by smallholder farmers (Table 4-4). Such adaptation practices believed increased the resilience against climate change, particularly for an increase in climate variability like prolonged periods of drought, and seasonal shifts in rainfall. It also maintains production under changing rainfall patterns, such as changes in the timing of rains or erratic rainfall patterns. In addition, adaptation measure like incorporation of crop residue improves soil fertility and water holding capacity of the soil (FAO 2009).

Table 4-4: Adaptation measures in crop and livestock production (% of respondents)

Adaptation Measures	Highland	Midland	Wetland	Lowland	Total	χ^2-value
Crop						
Crop diversification (Increasing the number of crops produced)	37.9	46.3	13.7	5.3	25.8	56.38***
Using new crop varieties	44.2	69.5	60	29.5	50.8	35.42***
Adjusting date of planting	32.6	42.1	23.2	33.7	32.9	7.76*
Use of early maturing crop varieties	17.9	29.5	14.7	44.2	26.6	26.04***
Use of drought tolerant crop varieties	15.8	22.1	4.2	40.0	20.5	36.58***
Use of disease/pest tolerant crop varieties	6.3	11.6	0	0	4.5	20.87***
Incorporation of crop residues	17.9	44.2	40.0	48.4	37.6	22.45***
Planting high value fruit trees	6.3	0	0	0	1.6	18.28***
Livestock						
Livestock diversification (Increasing the type of animals kept)	15.8	24.2	14.7	4.2	14.7	15.24**
Changing the type of animals kept	0	7.4	0	9.5	4.2	17.23***
Reducing the number of animals kept	41.1	24.2	10.5	17.9	23.4	26.93***
Sale weak and old animals before the outbreak of long dry season	49.5	55.8	12.6	30.5	37.1	46.59***
Keeping improved animals breeds	2	0	0	0	0.5	6.03
Practicing improved animal feed production/planting trees for animal feed	8.4	14.7	0	0	5.8	26.84***
Moving with animals in search of pasture and water	0	12.6	0	0	3.2	37.18***

Note: *** indicates significance at 0.01, ** at 0.05, and * at 0.10 probability levels.

Measures implemented by farmers in the livestock sub-sector includes: i) sale weak and old animals before the outbreak of long dry season (37.1% of respondents), ii) reducing the number of animals kept (23.4% of respondents), and iii) livestock diversification (14.7% of respondents). Small number of farmers also practiced improved animal feed production/planting trees for animal feed (5.8% of respondents), changed the types of animals kept from cattle to small ruminants (4.2% of respondents), moved with animals in search of pasture (3.2% of respondents), and kept improved animal breeds (0.5% of respondents) as an adaptation strategy. Significant statistical differences observed among the four agroecosystems in terms of almost all adaptation measures used (Table 4-4). Many authors including (FAO 2009; Deressa et al. 2009; Bryan et al. 2011; Woldamlak 2012) have mentioned the above widely used adaptation strategies in different parts of Ethiopia & Africa.

4.3.2.2 Adaptive responses through water and other natural resources

Agricultural management practices that increase agricultural production and reduce production risk also tend to be support climate change adaptation as they increase agricultural resilience and reduce yield variability under climate variability and extreme events, which might intensify with climate change (Bryan et al. 2011). Such activities implemented both at household and community levels to adapt to the changing climatic conditions and local environmental change more broadly. Management practices undertaken at household level include crop rotation, contour plowing, intercropping, manure preparation and application, and land management activities.

Of the different adaptation measures implemented at household level crop rotation and contour plowing activities practiced almost by the entire respondents. Out of the soil management activities that include intercropping, compost preparation, and manure heaping practiced by 21.3%, 26.9%, and 15.9% of the total respondents respectively. Similarly, physical and biological soil and water conservation activities like soil and stone bunds, water way, check dams, and planting of trees carried out by 44%, 32.1%, 25.3%, and 45% of the total respondents respectively. Irrigation practiced by about 22.6% of the respondents. In almost all of the conservation adaptation measures applied at household level, statistically significant different observed among the four agroecosystems (Table 4-5).

Table 4-5: Soil and water management measures used in individual farm (% of respondents)

Adaptation Measures	Highland	Midland	Wetland	Lowland	Total	χ2-value
Crop rotation	90.5	99	85.3	99.0	93.5	21.03***
Intercropping	17.9	23.2	11.6	32.6	21.3	13.41***
Compost preparation	26.3	24.2	7.4	49.5	26.9	43.48***
Manure heaping	29.5	21.1	11.6	0	15.6	34.89***
Contour plowing	100	94.7	92.6	95.8	95.8	6.79
Irrigation practice	31.6	16.8	42.1	0	22.6	54.53***
Soil & Stone bunds	43.2	32.6	34.7	65.3	44.0	25.75***
Water ways/Cut of drain	43.2	9.5	42.1	33.7	32.1	32.11***
Check Dam	21.1	32.6	35.8	11.6	25.3	18.63***
Planting trees	35.8	29.5	37.9	76.8	45.0	53.36***

Note: *** indicates significance at 0.01probability levels.

Likewise, community level interventions to create assets include physical and biological soil and water conservation measures, afforestation and reforestation activities, and river diversion activities for traditional small-scale irrigation activities. Among the total respondents majority of them participated in the adaptation measures implemented at the community level: soil and water conservation (81.6%) and afforestation/reforestation activities (78.4%). The relative high number of household participation in community asset creation attributed by the fact that such adaptation measures coordinated and implemented by District and Kebele government officials as a planned adaptation strategy. Statistically significant difference observed among the four AES in participation of river diversion by the community (Table 4-6). The result revealed community participation in river diversion is higher in highland AES, where as nil in the lowland AES, which is simply the result of have no access to such irrigation schemes in this specific AES. This shows the prevailing agro-ecological conditions and available environmental resources influence options for agricultural adaptation.

Although rainwater storage in the soil (in situ) or in any reservoir (ex situ) is widely promoted adaptation option to climate change in Ethiopia and elsewhere, it was hard to find such intervention in the study area. Such water based intervention promoted as an adaptation strategy by smallholders farmers because it offer a suitable means for upgrading rainfed agriculture through in situ soil moisture conservation and on-farm runoff storage for complete and supplementary irrigation (Mahoo et al. 2013). Additionally, rainwater-harvesting techniques can prevent degradation of natural resources through reduced soil erosion especially in the fragile highland agroecosystems.

Table 4-6: Adaptation through water & other natural resource management: community asset creation (% of households)

Adaptation Measures	Highland	Midland	Wetland	Lowland	Total	χ2-value
Participating in soil and water conservation with community	87.4	82.1	71.6	85.3	81.6	9.31*
Participating in afforestation/ reforestation with the community	76.8	86.3	78.9	71.6	78.4	6.28
Participating in river diversion with the community for irrigation	40.0	16.8	18.9	0	18.9	49.89***

Note: *** indicates significance at 0.01, and * at 0.10 probability levels.

Asset creating collective action based adaptation measures like watershed land and water management activities increases the resiliency of the systems. Once the resilience of the systems enhanced the adaptive capacity increased. Adaptive capacity means the whole of capabilities of systems, resources and institutions of a country/region to implement effective adaptation measures to varied changes (Smit & Pilifosova 2003; MEA 2005; IPCC 2014). Therefore, such type of measures should be encouraged and supported as a planned adaptation measure.

Generally, the adaptation measures implemented in the study area until now are not adequate to meet the impending challenges situate by climate variability and change. According to EPCC (2015), climate change has been happening and will continue to happen with severe impacts on crop and animal production as well as on food security and the national economy. Based on our observation of the area and as verified during focus group discus there is high encroachment of agricultural land to the forest and grazing land use system in the area. These aggravated the land degradation problem found in the highland AES, and flooding and siltation problem in the wetland AES including the hydropower dams. Recent studies have shown that flood hazard is increasing in the highland areas due to changes in land use/land cover, rainfall pattern, and drainage (Kassa 2014). Therefore, any planned adaptation approach implemented in the area should incorporate forms of land use and land use change, and targeted payment for environmental services.

4.3.2.3 Intensity of adoption of adaptation measures at the household level

The sample households totally utilized 27 adaptation measures in response to the perceived climate variability and change. To know the intensity of adoption of adaptation measures, composite index of adoption (CIA) computed by utilizing the total number of adaptation measure a single farmer practiced from the possible available options. The adaptation measures implemented vary from AES to AES. The most widely practiced adaptation measure in all the AESs is contour plowing (96%) followed by crop rotation (94%). The least implemented adaptation measures are keeping improved animal breeds (1%) and planting high value fruit trees (2%) found only in the highland AES. Of the total adaptation strategies identified in the sub-basin (27), the actual implemented strategies by farmers range from 3 to 15 and the overall mean is 8.7. This shows that the intensity of adoption of adaptation measures by farmers in the sub-basin is below average. Adaptation is a process and its outcome affected by many factors and widely varies between countries, communities, and over time. Factors that influence adaptation of smallholder farmers' include farmers' characteristics, extension services, social networks, financial services, and technological factors. These groups of factors are not only influencing adaptation but also responsible for difference choices of adaptation strategies and behaves differently in different countries and regions depending on the level of development (Rass 2006).

When we evaluate the sub-basin based on percentage of farmers practicing certain type of adaptation measures, on average 32% of farmers adopted certain adaptation measures. The value is higher 35%, 34%, and 33% for midland, highland, and lowland AESs respectively. Whereas, the corresponding value for the wetland AES is below the average (27%). Relatively, farmers found in the midland AES implemented higher number of adaptation strategies from the available list of options. The calculated value of CIA for midland, highland, lowland, and wetland AESs were 0.36, 0.34, 0.32, and 0.26 respectively. The CIA value is higher for midland AES and lower for wetland AES as compared to the other AESs. Although, the surveyed farmers at least practiced three adaptation strategies, the overall result of the finding verifies that the adoption of the adaptation measures is below average.

From the result, one can conclude that there is extrication between farmers' perceptions of climate variability and change, and actual adaptation level. Despite significant number of farmers' perceived changes in temperature (about 93%) and rainfall (about 88%), the number of farmers adopted certain adaptation measures are below average. The finding supports some previous study conducted in Ethiopia (Deressa et al. 2009; Bryan et al. 2009). According to Deressa et al. (2009), almost half of their surveyed farmers in the Nile Basin of Ethiopia (n = 1000) did not attempt to adapt to climate change and variability. Similar result also obtained by Bryan et al. (2009) in which 37% of respondents did not adapt to perceived climate change.

Whereas study conducted by Arragaw & Woldeamlak (2017) in central highlands of Ethiopia revealed that more than 63% adapted certain adaptation measures.

4.3.3 Barriers to Adaptation

Barriers are the interaction of complex of factors that influence adaptation. According to Islam et al. (2014), barriers that hamper adaptation are a function of "the people involved, the nature of the specific systems involved and/or the larger context in which the people and systems operate". On the other way Biesbroek et al. (2013) views barriers as factors and conditions that emerge from the actor, the governance system or the system of concern. From this, it is apparent that barriers are the interaction of complex of factors that influence adaptation. Respondents in the study area mentioned many factors that hindered them in the adoption of adaptation measures. Among which knowledge and information are the most frequently cited barrier in the study area (75%). Other barriers include lack of/ insufficient supply of modern agricultural inputs (like improved seed, fertilizer, & crop protection inputs) (68%), labor shortage (55%), low potential for irrigation (48%), lack of finance (47%), and lack of technical support (22%).

Survey result supported by FGDs and KIIs in all agroecosystems. During FGDs, farmers raised the issue of free grazing animals for the low level of adoption of biological & physical soil and water conservation measures. Lack of adequate information and technical support is another area that farmers broadly speaking about for lack of effective adaptation strategies. This implies that farmers in the area requires to raise their level of awareness about changes of the climate condition, implement controlled grazing and create the possibility of better access to technologies to cope with the changes and/or adapt to it. Statistical significant differences observed among the four agroecosystems in terms of almost all adaptation barriers (table 4-7). Similar studies conducted in other parts of the country obtained almost similar results despite the difference in the order of their influence that vary across the areas (Deressa et al. 2009; Arragaw & Woldeamlak 2017; Getachew et al. 2018)

Table 4-7: Barriers affecting adaptation to climate variability & change (% of respondents)

Adaptation Barrier	Agroecosystems				Mean	χ2-value
	Highland	Midland	Wetland	Lowland		
Lack of knowledge & Information	71.6	61.1	77.9	88.4	74.8	19.85***
Lack of modern agricultural inputs	65.3	58.9	67.4	80.0	67.9	10.19**
Labor shortage	67.4	44.2	35.8	71.6	54.8	35.0***
Low potential for irrigation	29.5	50.5	18.9	92.6	47.9	121.2***
Lack of finance	49.5	41.0	40.0	58.9	47.3	8.87*
Lack of technical support	18.9	14.7	22.1	30.5	21.6	7.51*

Note: *** indicates significance at 0.01, ** at 0.05, and * at 0.10 probability levels.

4.4Conclusion and Policy implications

This study examined farmers' perception of climate variability and change, the impact of climate variability and change on agriculture sector, adaptation measures taken by smallholder farmers and barriers faced during the course of adaptation in four agroecosystems of the Fincha sub-basin. It is evident that the majorities of farmers in the sub-basin are aware of warmer temperatures and changes in rainfall patterns and overall decrease of the annual total rainfall. Farmers' perception of increased temperature and changes in rainfall pattern evidenced by metrological data, whilst decreased in annual total rainfall not proofed. The main impact of the change on crop & livestock production as reported by respondents include decline in length of growing period, the decreased and variability of water availability, increased crop damage by insects and pests, increased infestation of weeds, and increased incidence of livestock disease.

To respond to these changes, farmers have adopted a range of measures like crop diversification, planting different crop varieties, changing planting and harvesting dates to correspond to the changing pattern of rainfall, irrigation, implementing different land management measures, and different biological and physical soil and water conservation measures. The adaptation measures implemented until now are not adequate to meet the impending challenges situate by climate variability and change. There is also extrication between farmers' perceptions of climate variability and change, and actual adaptation level. Despite significant number of farmers' perceived changes in temperature and rainfall, the number of farmers adopted certain adaptation measures are below average. The finding also revealed the presence of multiple barriers that hindered the adoption of available adaptation measures.

These necessitate that there is a need for planned interventions to identify and support effective adaptation measures. Some of the possible interventions include increase the awareness of the community, investments in integrated natural resources management, dissemination of improved and suitable crop varieties, agroecosystem specific in situ & ex situ rainwater harvesting technique, crop diversification, and integrated pest control are some to mention. It is also obvious that such interventions should build on farmers' knowledge by following farmer-participatory processes.

5. SOIL EROSION HAZARD ASSESSMENT FOR CONSERVATION PLANNING AT WATERSHED LEVEL: THE CASE OF NESHE DAM WATERSHED

ABSTRACT

Soil erosion recognized as one of the world's most serious environmental and economic problems of the world. Like other highland parts of Ethiopia, the anthropogenic caused soil erosion by water is the major factor for soil loss in the area. To trigger the urgent policy intervention of sustainable land management, the study of annual soil loss is inevitable. Therefore, the research integrates the Revised Universal Soil Loss Equation (RUSLE) with a Geographic Information System (GIS) to analyze the amount of soil loss in Neshe Dam watershed of the Abbay basin of Ethiopia. The result of the analysis revealed that the total amount of soil loss from the watershed is about 1,252,935 ton per year from 33,376 hectares. The result also illustrated that the potential annual soil loss of the watershed ranges from 0.0 to 350.93 t ha^{-1} yr^{-1}. Average annual soil loss for the whole watershed anticipated at 37.54 t ha^{-1} yr^{-1}. In terms of sub-watersheds, the result portrayed that very high soil loss (56.62 t ha^{-1} yr^{-1}) observed in sub-watershed B accounts (16.3%) and the least (16.06 t ha^{-1} yr^{-1}) observed in sub-watershed E accounts (23.6%). The study also conclude that if proper measures not taken now to protect the watershed through appropriate soil and water conservation measures, the accelerated erosion-taking place in the watershed jeopardize the agricultural production within the watershed and energy generated from the dam in the long term.

Key Words: Neshe Dam, Soil erosion risk, Watershed, RUSLE, GIS

5.1Introduction

Soil erosion recognized as one of the world's most serious environmental and economic problems of the world (Pimentel et al. 1995; Lal 2001; Hurni et al. 2015). Soil erosion is a complex dynamic process that involves the detachment, transportation, and deposition of soil particles on the earth's surface (Jain et al. 2001). Water, wind, sea waves, humans and animals are the main agents involved in the process of soil erosion (Merritt et al., 2003). Through the processes, it causes loss of fertile topsoil, reduces the productive capacity of the land, and thereby creates risk to global food security (Zhou et al. 2008; Bewket and Teferi 2009; Wang et al. 2009). Globally, about 80% of the current agricultural land degradation caused by soil erosion (Angima et al. 2003). Of all the processes leading to land degradation, water erosion accounts 56% of the total degraded land surface of the world (Oldeman et al. 1990). In Ethiopia, the rate of soil loss by water ranges from 16 to over 300 t ha^{-1} yr^{-1}, depending on the degree of slope gradient, types of land cover, nature and intensities of rainfall (Tesfaye et al. 2014).

Soil erosion can be either natural or geological erosion, a slow process occurring since the early period of the earth; or accelerated erosion, faster and relatively a recent phenomena happening because of humans' unwise use of resources. A number of anthropogenic factors such as deforestation, overgrazing, incorrect methods of tillage, and unscientific agricultural practices exacerbated the destructive processes of accelerated soil erosion (Lal 2003; Nyssen et al. 2004; Zhou and Wu 2008). It generates strong environmental impacts and major economic losses from decreased agricultural production to the off-site effects on infrastructure, design-life of constructed reservoirs and dams, and quality of surface water resources by sedimentation processes (Amsalu et al. 2007; Bewket and Teferi 2009; Haregeweyn et al. 2017).

In Ethiopia, where agriculture is the main economic stay of the people, soil erosion by water becomes a big threat to the sector and overall economy of the country (Sonneveld 2002; MoARD and World Bank 2007; Bewket and Teferi 2009; Hurni et al. 2010; Hurni et al. 2015; Haregeweyn et al. 2017). Out of the estimated total agriculturally productive lands, about 27 million hectares are significantly eroded, 14 million hectares are seriously eroded and 2 million hectares have reached the point of no return, with an estimated total loss of 2 billion m^3 of top soil per year (Bewket and Sterk 2003; Bobe 2004). Similarly, Sonneveld (2002) estimated the economic cost of soil erosion is about US$ 1.0 billion per year; while MoARD and World Bank

(2007) estimates that the minimum annual cost of soil erosion ranges between 2 and 3 per cent of the national agricultural gross domestic product (GDP) of Ethiopia.

According to Hurni (1988), the average soil loss in Ethiopia is about 42 tons per hectare per year from farmlands and causes an average annual reduction in soil depth of 4 mm, while the average global soil loss from farmlands is 15 tons/ha/year (Lulseged and Paul 2008). Even though this loss will often reappear as fresh sediments deposited downstream, the areas that benefit from the transported soil is relatively small as compared to those from which it is removed (Sonneveld and Keyzer 2002). Conversely, it causes serious environmental problems in the downstream of the watersheds by depositing sediments in farmland, rivers, lakes, and reservoirs. Additionally, it also causes decline in esthetic quality of the landscape, increase in the probability of flood in downstream, increase risk of food insecurity, loss of aquatic biodiversity in rivers, lakes and reservoirs by pollution, eutrophication, and turbidity (Zhou and Wu 2008; Zhou et al. 2008; Bewket and Teferi 2009; Wang et al. 2009). This clearly shows how Ethiopia is prone to the problem of soil erosion.

Therefore, to avert the environmental, social, and economic consequences of soil erosion, it requires an in-depth understanding of the risk, extent, and spatial distribution of the problem. To do such assessment and analysis, different models have developed and applied in different parts of the world. These models majorly classified into physical based models and empirical based models (Bhattarai and Dutta 2007). Physically based models such as WEPP, the Areal Nonpoint Source Watershed Environmental Resources Simulation (ANSWERS), and EUROSEM investigate erosion processes by synthesizing individual components (Bhattarai and Dutta 2007). Empirical based models such as Universal Soil Loss Equation (USLE), the Modified Universal Soil Loss Equation (MUSLE), and the Revised Universal Soil Loss Equation (RUSLE) are the most commonly used methods to predict soil erosion especially at watershed scales. Though the physical based models provide enough understanding of spatial and temporal situations of soil erosion, the Empirical based models are commonly used methods due to their minimal data requirements and ease of application (Lal 2001; Bhattarai and Dutta 2007; Bewket and Teferi 2009; Zhang et al. 2009).

The USLE is an empirical model developed to predict the long-term average annual rate of soil erosion from agricultural fields in the United States of America using various factors including topography, rainfall pattern, soil type, crop system, and management practices (Wischmeier and Smith 1978; Renard et al. 1997; Zhou and Wu 2008; Kouli et al. 2009). However, used widely all over the world including in Ethiopia either in the original, modified, or revised form (Hurni 1985; Hellden 1987; Mellerowicz et al. 1994; BCEOM 1998; Spaeth et al. 2003; Bhattarai and Dutta 2007; Bewket and Teferi 2009; Nigussie et al. 2012; Ali and Ahmet 2012; Aswathy and Indulekha 2018). Even though the model originally developed for predicting soil erosion at the field scale, its revised version in cooperation with GIS and remote sensing (RS) tools has enabled application for large areas and satisfactory results have been reported (Mellerowicz et al. 1994; Zhou and Wu 2008; Zhang et al. 2009; Nigussie et al. 2012; Ali and Ahmet 2012). The GIS and remote sensing (RS) tools in cooperation with RUSLE provide an in-depth analysis of individual factors such as soil type, slope, and land use; and used for delineation of erosion prone areas and prioritization of sub-watersheds for a targeted and cost-effective conservation planning purposes (Bhattarai and Dutta 2007; Zhou and Wu 2008). In this study, we used RUSLE model under a GIS framework to estimate soil erosion in the Neshe Dam Watershed.

The central highland region of Ethiopia, where the Neshe dam watershed situated, is particularly prone to soil erosion due to topographic, soil properties, land cover, climatic, and anthropogenic factors. Topographical and climatic characteristics of the region such as having a steep slope and erosive nature of rainfall coupled with prolonged anthropogenic effects have made the region very susceptible to soil erosion (Nyssen et al. 2008, 2009; Bewket and Teferi 2009; Nigussie et al. 2012).

Therefore, the objective of this study was to examine the state of soil erosion and the subsequent sedimentation of the Neshe Dam watershed in the Blue Nile River basin, which is one of the hydroelectric and Irrigation water supply infrastructures of the country. The study demonstrate erosion assessment model, Revised Universal Soil Loss Equation (RUSLE), integrated with satellite remote sensing data and geographical information systems that provide useful incite for conservation decision-making. The study also identifies areas of high erosion loss in the watershed for prioritized actions.

5.2 Description of Study Area: Neshe Dam Watershed

5.2.1 Biophysical Setting of Neshe Dam Watershed

Neshe Multipurpose Dam project is located about 350 Km northwest of Addis Ababa, in the Fincha'a sub-basin of the Blue Nile river basin. The Blue Nile, also known as the Abbay River, drains most of the north-central and northwestern parts of Ethiopia. The watershed is situated in the south-central part of the Blue Nile (Abbay) River Basin in Fincha'a sub-basin, between the latitudes 9^0 35' N and 9^0 52' N, and longitude 37^0 00' E and $37^0$20' E (Figure 5-1). The watershed area is north from the existing Amerti Reservoir and Finca'a reservoir between the towns of Shambu and Fincha'a, and to the west of the Fincha'a Sugar estate.

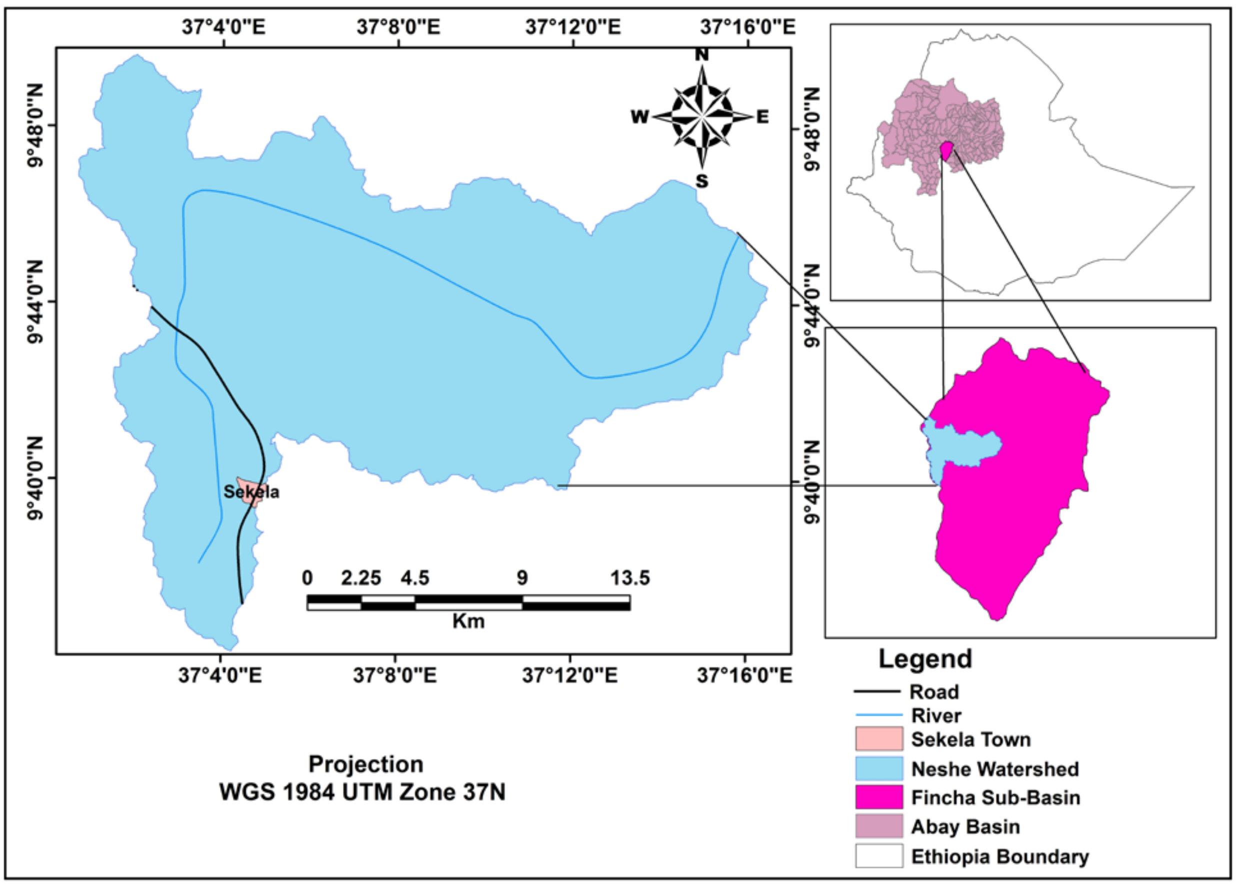


Figure 5-1: Location of the Study Area

The Neshe River valley starts on the highland plateau northeast of the town of Shambu and runs from west to east for about 10 km and then in a northerly direction for further 7 km. The valley elevation is above 2,200 masl, with the surrounding ridges extending to 2810 masl. The dam site located close to the escarpment and the reservoir impound most of the Neshe valley. The drainage area of the watershed is about 333.76 km^2 and according to the Ethiopian Electric Power [EEP] (2005), feasibility study report the total storage volume of the reservoir is 448 million m^3.

Climate: The Neshe Dam watershed area is located on the highland plateau at an elevation of above 2,200 masl. The plateau characterized by a subtropical climate, with an average annual rainfall of about 1,609 mm, and with an average minimum and maximum air temperature of 11.5^0C and 23.9^0C respectively. Maximum temperature observed from February to April while the minimum recorded in July to August. The relative humidity is highest in July to September with the minimum in February to April. The main wet season occurs between June and September, followed by a dry season that interrupted by short rainy period between February and April (known as the Belg season). The movement of the Inter-Tropical Convergence Zone, which causes most of the annual precipitation to fall over four summer months, determines the rainy season. Rainfall during the rainy season is in the order of 200 to 324 mm/month, with very little rainfall occurring during the rest of the year. Agro-ecologically, the watershed lies in the Dega and Woyna-Dega agro-climatic zone. There is no metrological station within the watershed and the average annual rainfall, maximum and minimum temperature data obtained from the surrounding metrological stations (Neshe, Homi and Shambu).

Hydrology: According to EEP (2005), the Neshe river flows have been measured since 1963. The record indicates the average long-term flow was 5.87m^3/s or 183 million m^3 per year of which about 90% of flow volume occurring during the summer months (June to September). Flood peaks occur during the rainy season and are relatively modest for the respective watershed areas, which is the result of the retention of flood by large flat swampy zones. The Neshe river highest flows recorded from July to October, when the floods regularly exceed 20m^3/s. The highest flood of 65m^3/s was recorded in July 1990 and floods during the rest of the year are small and in the order of a few m^3/s. From the limited number of suspended sediment samples at the Neshe river, it appears that the sediment transport is modest compared to the Ethiopian average. This further explained by the low river gradient on the highland plateau and the widely presence of swamps.

Topography: The Neshe watershed is located in the Western part of Central Ethiopia, in the physiographic region of the Ethiopian highland plateau, within the Blue Nile (Abbay) basin approximately 350 km North West of Addis Ababa. The plateau situated at elevations between 2206 to 2810m.a.s.l and characterized by rolling topography interspersed with high mountain ranges, volcanic cones and deep gorges, which divide the Neshe River from adjacent watersheds (Figure 5-2). The surface of the Upper Neshe Valley is a wide, flat-bottomed, grassland and swampy area. At the end of the valley, the Neshe River descends approximately 600m over a steep escarpment and a series of waterfalls and rapids to the confluence of the Fincha'a River, a major tributary of the Blue Nile River.

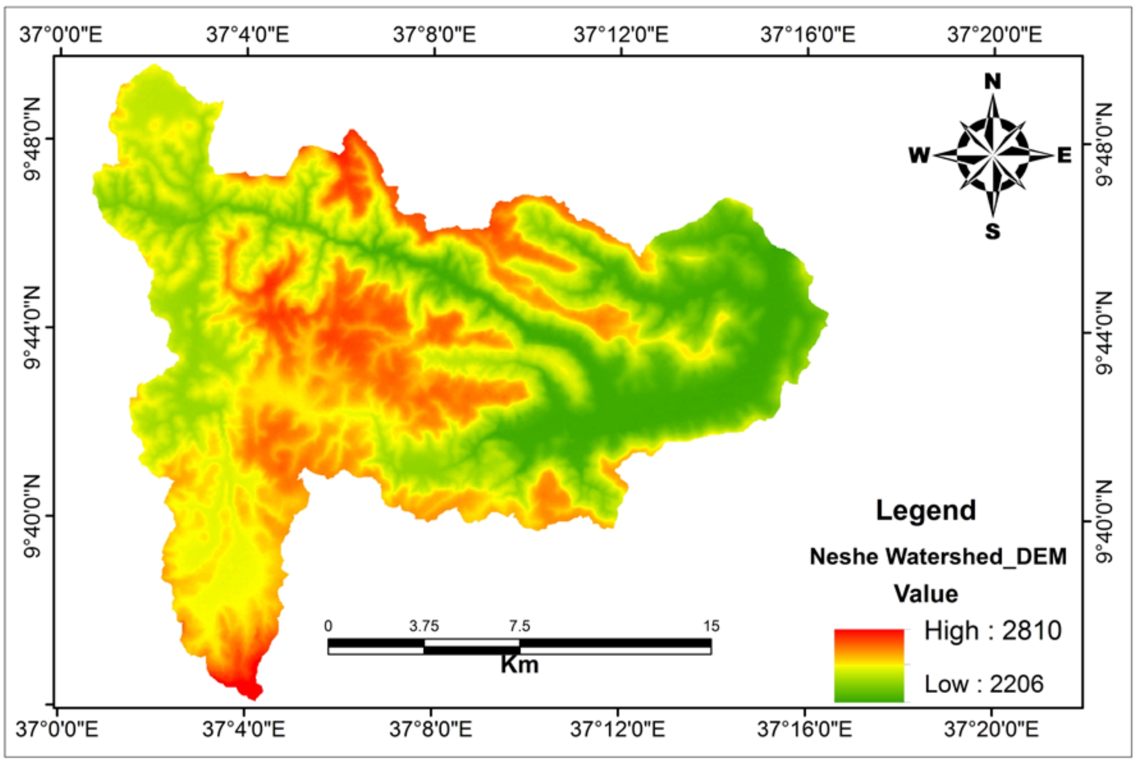


Figure 5-2: DEM of the Neshe Dam Watershed

Geology and Soils: The watershed area predominantly underlined by Mesozoic sedimentary formations consisting of horizontally bedded sandstones and shales of the Adigrat formation (Jurassic age). The sandstone units form the ridges surrounding the upper Neshe valley and the vertical cliffs of the escarpment below Neshe falls. The Adigrat formation lies unconformable at the top of the Precambrian basement complex, which outcrop along the Neshe River in the lower valley. The Adigrat formation overlain by Tertiary age inter-valley basalt of the trap series that deposited in a previous erosional valley in the Adigrat formation in the upper Neshe valley. The inter-valley basalt has retarded erosion and entrenchment of the river, resulting in the flat, poorly drained, swamp areas of the upper valley (EEP 2005; Denekew and Bekele 2009).

Soils reflect the underlying geology and degree of slope. Leptosols underlie the steep slopes of the watershed ridge. It is shallow, often gravelly with low water holding capacity, and very prone to erosion. On the plateau and the flatter areas in the gorge are extensive areas of Nitosols. Their fertility is relatively high with relatively good soil moisture holding capacity.

Land Use and Land Cover: The most widespread land cover is rain-fed cultivation covering 63.5 percent of the watershed. Forest and woodland, Grazing land, Water body, and settlement area accounts 18.1, 10.8, 7.0 and 0.6 percent of the total respectively (Table 5-1). The water cover is the result of the hydroelectric dam constructed by the government for power generation in 2011. The cultivated fields situated on the steep and undulating slopes of the watershed and not protected from water erosion by any soil and water conservation measures. The farming system of the watershed is mixed farming with dominantly oxen plough cereal crop production and livestock rearing.

Table 5-1: Neshe Dam Watershed Dominant land cover

Sr. No.	Land Cover	Area (Km^2)	Area (%)
1	Rainfed Cultivation	211.98	63.5
2	Forest	60.53	18.1
3	Grazing Area	35.95	10.8
4	Water Body	23.51	7.0
5	Settlement Area	1.79	0.6
Total		**333.76**	**100**

The vegetation coverage of Neshe watershed includes patches of scattered vegetation and trees. The shrub and tree species observed in the watershed area includes but not limited to *Acacia abissinica, Acacia nilotica, Cordia africana, Carissa edulis, Celtisafricana, Albizia gumifera, Croton macrostachyus, Dodonaea angustifolia, Ekebria cafensis, Ficus sycomorus, Ficus vasta, Hygenia abissinica, Maytenus arbutifolia, Olinia rochetiana, and other species.* There are also grass species, which constitute the floating mass.

It is obvious that Vegetation in a watershed plays multiple jobs that include intercepting raindrops, reducing surface runoff, and there by control erosion, maintain soil fertility and regulate the microclimates. It also helps to enrich ground water sources. However, much of the natural vegetation in the area either deforested or altered by extensive cultivation and human settlements.

5.2.2 Socioeconomic Setting

The Neshe Watershed administratively located in Oromia regional state, Horo Guduru Wollega Zone of Horo, Abbay Chomen, and Jardega Jarte Woredas. Specifically, most parts of the reservoir of the dam lay in Sandabo Dongoro and Homa Kulkula Kebeles[5] of Abbay Chomen Woreda and Ejersa Maecha, Alishia Eggu and Haro Aga Kebeles of Horo Woreda. According to sources, the total population living in these five Kebeles estimated to be about 5,229. Of which 3,170 are males and the remaining 2,059 constitute female population.

Based on the data obtained from the area about 98% of the population is from Oromo ethnic group. The remaining belongs to Amhara ethnic group. In the project area, Oromifa is the dominant language. The community settled on the surrounding hillsides of the river valley, the community builds their houses in clusters and dispersed manner. The types of houses built are tin roofed and tukuls.

The major means of livelihoods for people residing in the watershed include crop and livestock production, use of Natural resources and small businesses. The major crops grown in the area include Tef (*Eragrostis tef*), Maize (*Zea mays*), Barley (*Hordeum vulgare*), wheat (*Triticum aestivum*), Faba bean (*Vicia faba*), and field pea (*Pisum sativum*). According to sources from the Woreda agricultural offices, the major domestic livestock populations used as means of livelihood include and verified during field survey was cattle, goat, sheep, horse, mule, donkey and poultry. Livestock provides meat, milk, butter, hides and eggs production for means of livelihood and income generation. The community in the area uses forests for several purposes. To mention some various trees are used as both firewood and timber sources, and for honey production.

[5] The lowest tiers in the administrative structure of the country

5.3 Methodology

5.3.1 RUSLE Model and Soil Erosion Risk Analysis

The overall methodology involved the use of the RUSLE model in a GIS environment, with factors obtained from meteorological stations, soil surveys, topographic maps, Satellite Images, Digital Elevation Model and results of other relevant studies. In the processes, the GIS layers built for each factors of the model and combined by cell-grid modeling procedures in ArcGIS to predict soil loss in a spatial domain. The model used to estimate the average annual rate of soil loss from the watershed and to locate the special distribution of the erosion hot spot areas within the watershed (Farhan and Nawaiseh 2015).

The expected soil loss potential (erosion hazard) expressed as tone per hectare per year for the study area was determined using the RUSLE model in a GIS environment. The Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1978) is the most frequently used empirical soil erosion model worldwide. More recently, Renard et al. (1997) has modified the USLE into a Revised Universal Soil Loss Equation (RUSLE) by introducing improved means of computing the soil erosion factors. This method presents the possible soil loss as results of splash, sheet and rill erosions (Welle et al. 2007; Hui et al. 2010). It should be clear that the model (RUSLE) does not estimate deposition, sediment yield at a downstream location and ephemeral gully erosion and does not represent fundamental erosion processes and interactions (Kenneth et al. 1991).

The USLE has been widely used all over the world either in the same or modified forms. Hurni (1985) also used this model to assess soil erosion in Ethiopia. He even modified some factors of the USLE for Ethiopian conditions. Three of the most significant modifications include R (rainfall erosivity index), C (land cover) and P (management) factors. This was a valuable input to this research and other erosion research in Ethiopia since the 1980’s.

However, the available information in this regard is still generalization of the realities in different localities and does not show specific conditions. Therefore, there is a need to conduct a detailed and extensive assessment of erosion hazard by considering the various site-specific erosion factors into considerations. The control factors of soil erosion, namely: climate, soils, vegetation cover, topography and management combined in the empirical Revised Universal Soil

Loss Equation (Renard et al. 1997). The model estimates sheet and rill erosion as a function of six major factors:

$$A= R *K*LS* C* P \qquad \textbf{Equation (1)}$$

Where A is the average annual soil loss due to water erosion (t ha^{-1} yr^{-1}), R is the rainfall and runoff erosivity factor, K is the soil erodibility factor, LS is the slope length and slope steepness factor, C is the crop management or land cover factor and P is the erosion control practice factor.

Soil erosion hazard of the Neshe Dam Watershed determined by multiplying the respective RUSLE factor values (rainfall erosivity (R) factor, soil erodebility (K) factor, slope length & steepness (LS) factor, crop management (C) factor, and support practice (P) factor maps) interactively in ArcGIS® using equation (1) above. Arc GIS 10.1 and the associated packages utilized in the course of computation. Land use and land cover information for the watershed acquired from the LANDSAT 2018 ETM+ satellite image, Path 170 and Row-053 and used to classify the current land use and land cover map of the study watershed. The image has 30 * 30 meter resolutions. The land use and land cover was classified into five classes (forests, rain-fed cultivated land, built-up/settlement areas, grazing land and water body) based on the supervised classification systems.

Each factor calculated on the cell bases in order to recognize the spatial patterns of soil loss. Such a procedure enables the model to isolate small areas with a high erosion risk in the watershed, and to identify the role of individual RUSLE factors in the existing erosion potential (Millward and Mersey 1999). Through multiplying factor map layers in a GIS, the spatial distribution of soil erosion loss and severity maps/tables also generated. An assessment of the spatial relationships between soil erosion and environmental factors (i.e., soil, terrain units, elevation, slope, and land use/cover types) for the Neshe Dam Watershed was also established.

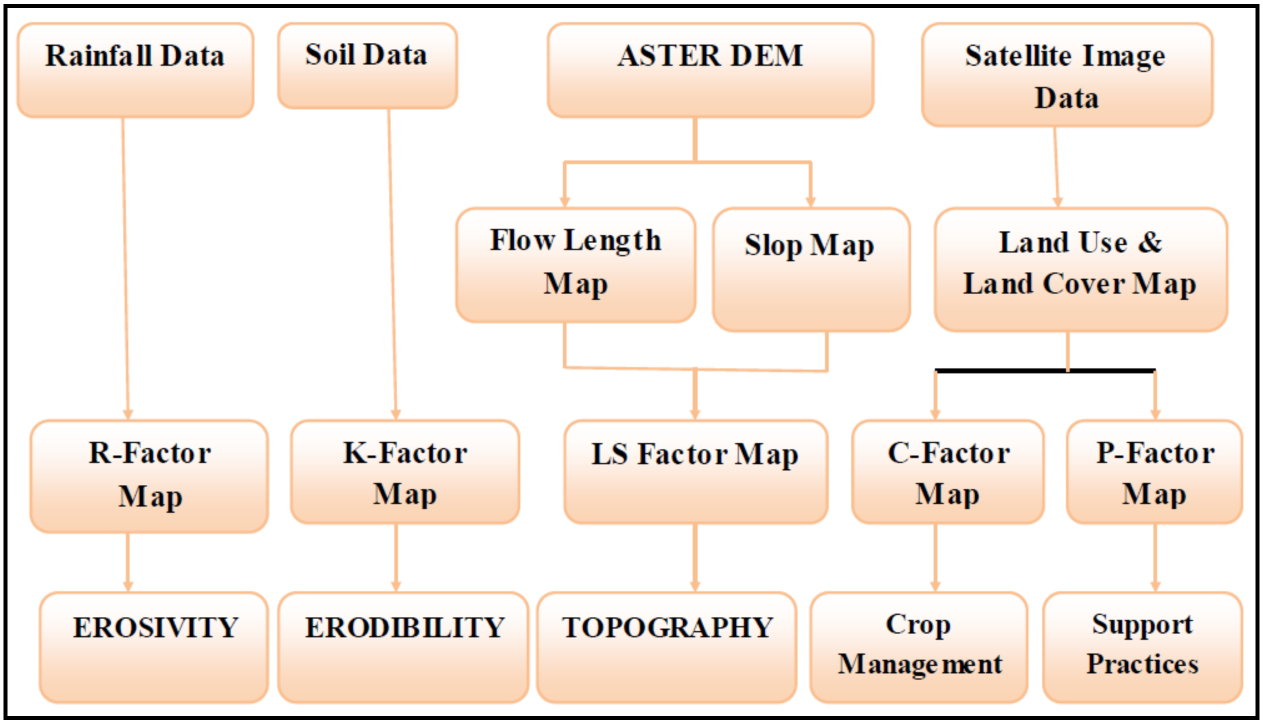


Figure 5-3: Flow Chart of Factor Layer Map Determination

5.3.2 Determining RUSLE & GIS Parameters

The RUSLE estimates average soil loss for a given area as a function of six major factors (Equation 1). The parameters used in the RUSLE model to estimate soil loss are rainfall erosivity (R), soil erodability (K), slope length and steepness factor (LS), cover management factor (C) and conservation practice factor (P) [Figure 5-3].

5.3.2.1 Rainfall Erosivity (R) Factor Layer

The rainfall erosivity (R-factor) is a measure of the erosivity of local average annual precipitation and runoff to cause soil erosion in a given circumstances. R factor often calculated as an average of EI-values measured over 20–25 years to enclose cyclical rainfall patterns (Angima et al. 2003). EI is a statistical interaction term that reflects how total energy and peak intensity are combines in each particular storm (Renard et al. 1997). RUSLE (and its predecessor USLE) designed to account for the effects of raindrop impact and subsequent overland flow on soil erosion (Cooley et al. 1988). Within the USLE, rainfall erosivity estimated using the EI30 measurement (Renard et al. 1997). However, rainfall kinetic energy and intensity data are not available in our cases. Therefore, the erosivity factor R calculated according to the equation given by Hurni (1985), derived from a spatial regression analysis (Hellden 1987) for Ethiopian conditions. The model adapted by Hurni for Ethiopian conditions based on the available mean annual rainfall data.

$$R = -8.12 + (0.562 \times P) \qquad \text{Equation (2)}$$

Where P is mean annual rainfall in mm.

In order to compute R factor using such formula for the project watershed three metrological stations with mean annual rainfall of 20 years have used. After having, the averaged 20 years rainfall data for each metrological station, kriging interpolation by ArcGIS 10.1 done to generate an estimated surface from these scattered set of point data into surface. In the study watershed, there was no metrological station that measure rainfall. So, R-value interpolated through annual rainfall data from surrounding metrological stations. The resulting R–Factor value map generated and presented in figure 5-4. Table 5-2 shows the Name, the location, duration of the data, mean annual precipitation and erosivity value of each of the metrological stations used in this study.

Table 5-2: Rain Gauge Stations considered around the study area

No	Station Name	Location			Available Data Duration		Average Annual Precipitation	Erosivity (R)
		Easting	Northing	Altitude	Starting	End		
1	Shambu	37.121167	9.571200	2460	1995	2015	1486.7	827.4
2	Neshe	37.268330	9.723330	2060	1995	2015	1756.6	979.1
3	Homi	37.241167	9.621333	2371	1995	2015	1585.8	883.1

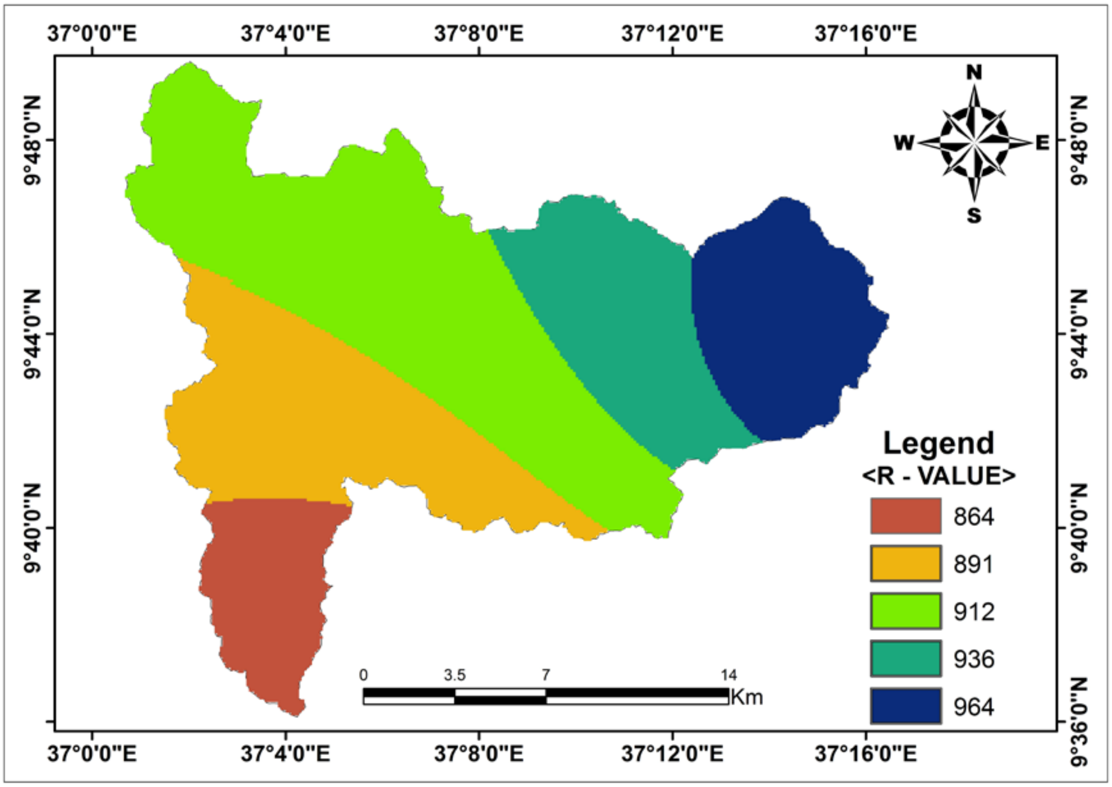


Figure 5-4: R-Factor Value Map

5.3.2.2 Soil Erodibility (K – Factor) Layer

The soil erodibility factor (K factor) measures the susceptibility of soil particles or surface materials to detachment and transportation by the amount of rainfall and runoff input (Renard et al. 1997). It is a function of the inherent properties of the soil in relation to the soil profile parameters that includes soil structure; soil permeability; and percent of silt, percent of sand and percent of organic matter content in the sample (El-Swaify and Dangler 1976). Thus, erodibility varies with soil texture, aggregate stability, shear strength, infiltration capacity and organic matter and chemical content of the soil (Morgan 2005). In terms of textural class, fine particles are resistant to detachment because of their cohesiveness, while large particles are resistant to transport because of the requirement of greater forces to entrain them. Consequently, soils with high silt and find sand content are highly erodible (Prasannakumar et al. 2011). The K factor ranges on a scale from 0 to 1, with 0 indicating soil with least susceptibility to erosion, and 1 refers to soils which are highly susceptible to erosion by water.

In Ethiopia, however, there is scanty of data to determine the required K factor values parameters. To overcome such data problem, Hellden (1987) adapted a qualitative index based on soil color (which believed to be a reflection of soil properties) to determine K factor values. Four different colors are recognized (black, brown, red and yellow) and their corresponding K factor values are 0.15, 0.2, 0.25 and 0.3 respectively. Similarly, the Soil Conservation Research Project [SCRP] (1996) suggested soil color as a method of K factor value determination.

Hence, the soil erodibility (K) factor for the study area estimated as a qualitative index that was adapted to Ethiopia by Hellden (1987) based on the color of the soil. According to FAO soil classification (1986), visual interpretation, survey and focus group discussion result of the area revealed Neshe Dam watershed covered majorly by two soil types that are brown or dark brown in the upper part of the watershed, and redish brown in the lower parts of the watershed.

The vector soil map of the study area clipped from the FAO soil map of Ethiopia with the study watershed using the spatial analyst tool in ArcGIS. Then, K value (0.2 for brown to dark brown and 0.25 for redish brown) assigned for each of the two soil types based on their colors. Higher value indicates more susceptibility while lower value indicates less susceptibility to erosion. Finally, the resulting vector soil map changed to grid file or raster with a cell size of 30 x 30 meters. The raster map then classified into two distinct classes based on their erodibility values and presented below in Figure 5-5.

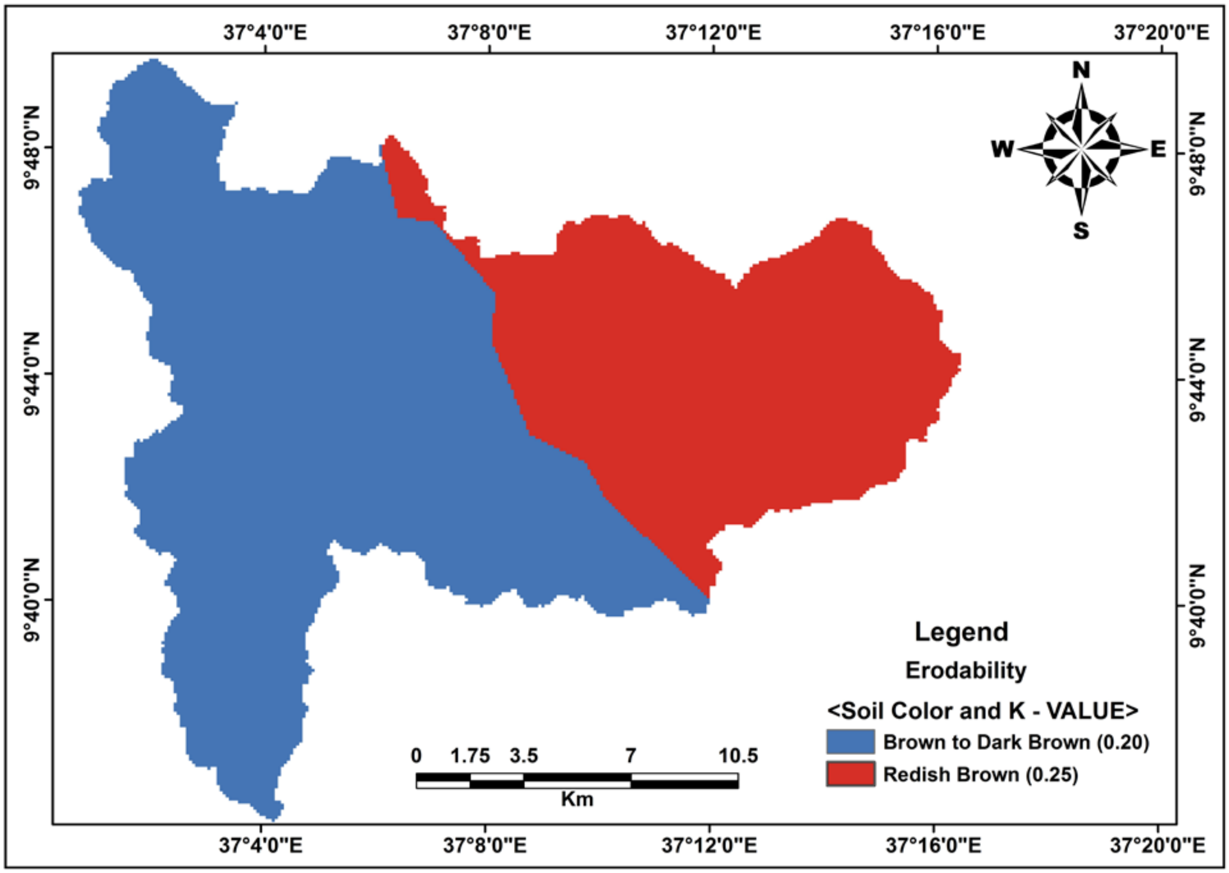


Figure 5-5: K - Factor Value Map

5.3.2.3 Slope Length and Steepness (LS – Factor) Layer

The effect of topography on soil erosion in RUSLE model accounted for by the LS factor that combines both the effects of slope length factor (L) and slope steepness factor (S). Erosion increases as slope length (L) increases due to the progressive accumulation of runoff in the down slope. Similarly, soil erosion increases as the slope steepness increases because of the increase in the velocity and erosivity of runoff (Wischmeier and Smith, 1978).

RUSLE represents the combined effects of rill and inter-rill erosion. According to Pradhan et al. (2012), rill erosion primarily caused by surface runoff and increases in a down ward slope direction because the runoff increases in this direction, and inter-rill erosion mainly caused by raindrop impact on soil surface and considered uniform along a slope. The (L) parameter expresses the ratio of rill erosion (initiated by flow) to inter-rill erosion (raindrop impact) to find the loss of soil in relation to the standard plot length of 22.1 m. The slope steepness factor (S) reflects the influence of slope gradient on erosion. Both slope length and steepness substantially affects sheet and rill erosion estimated by RUSLE. In erosion prediction, the L and S factors usually evaluated together. In this study, the flow length and slope gradient generated from the DEM using ArcGIS 10.1 spatial analyst tools arc hydro extension. Then the combined LS factor computed for the study watershed by means of raster calculator following the equation (3) in ArcGIS environment as proposed by Moore and Burch (1986a, b). Finally, the resulting LS factor map of the watershed calculated and its spatial distribution presented in figure 5-6 below.

The following equation (3) employed for calculating LS using DEM after preparing slope gradient map and the flow direction map to generate flow length map.

$$\mathbf{LS = (\lambda^{0.3}/22.1) * (S/9)^{1.3}} \qquad \textbf{Equation (3)}$$

LS = (POW (flow length, 0.3)/22.1) * POW (slope/9, 1.3)

Where λ = Flow length, S = Slope in percent, and LS = combined slope length and slope steepness factor. Two steps followed in raster calculator: First determination of $(\lambda^{0.3}) * (S/9)^{1.3}$ and second Division of the result of step one by 22.1. The LS factor value obtained in this study ranges from zero to 8.19.

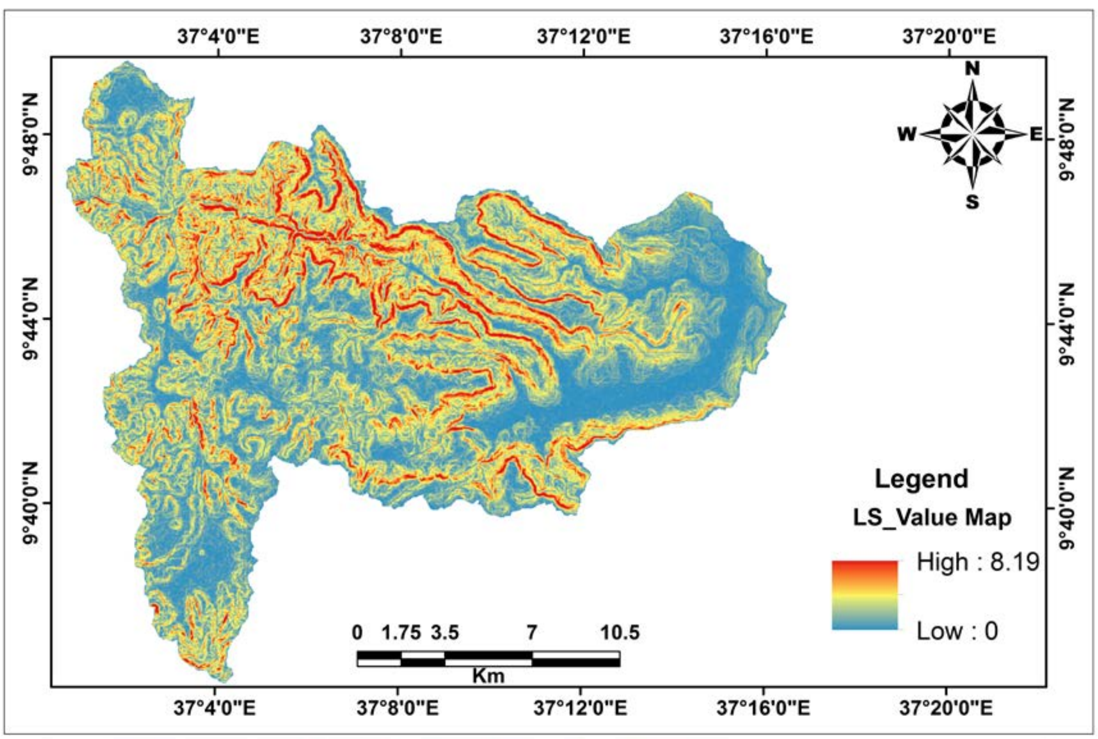


Figure 5-6: LS - Factor Value Map

5.3.2.4 Land Use/Land Cover (C – Factor) Layer

The C- factor measures the combined effect of all the interrelated cover/use and management practices on the runoff and soil erosion rate. It defined as the ratio of soil loss from land cropped under specific conditions to the corresponding loss from clean-tilled, continuous fallow (Wischmeier and Smith 1978; Renard et al. 1997). The parameter is the second most important factor (after topography) that controls soil erosion rates and decreases when the vegetation cover increases (Lu et al. 2004). The factor largely controlled by surface vegetation, land use, surface roughness and soil moisture (Farhan and Nawaiseh 2015). To estimate the cover factor LANDSAT ETM+ image acquired on 27 January 2018 from Earth Explorer USGS (30 m resolution) of Path-170 and Row-053 utilized.

In order to determine C - factor, the acquired satellite image was classified into five identified land use/cover classes (forest, rain-fed cultivated, grazing, built-up/ settlement area, and water bodies) by applying maximum likelihood of supervised classification method. Afterward, a field survey performed to verify and correct the results of the classification. During the field survey, ground truth data by Geographical positioning system (GPS) utilized to determine the level of classification for major land use types. Once the classification processes completed, the classified image changed into vector format and the corresponding C-value assigned as suggested in previous literatures using reclassify method in Arc GIS 10.1. As suggested by Hurni (1985) for Ethiopian condition, the C factor value for different land-use and land-cover classes as follows: 0.01 for forestland, 0.25 for tef dominated cultivated land, 0.05 for grazing land and settlement areas, and zero for water body. Finally, the C - factor value map produced by converting to raster formats (Figure 5-7).

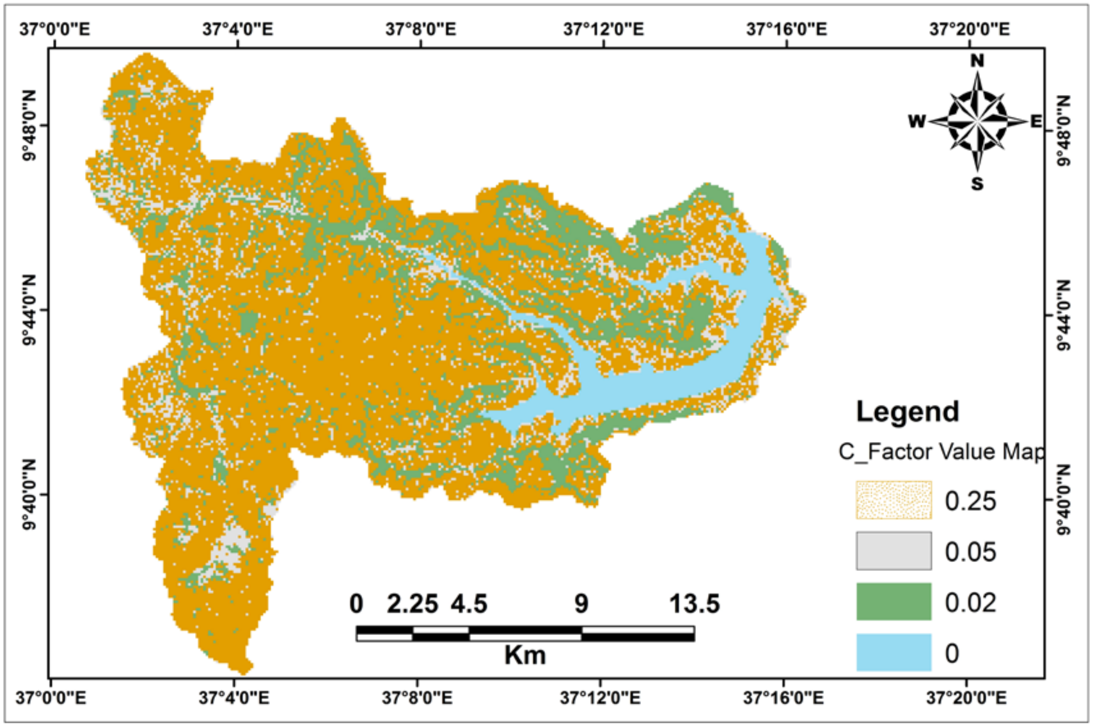


Figure 5-7: C - Factor Value Map

5.3.2.5 Management (Support) Practice (P) Factor Layer

The support practice factor (P) in RUSLE is the ratio of soil loss with a specific support practices to the corresponding loss with upslope and down slope tillage, which assigned a value of one and shows the worst-case scenario (Renard et al. 1997; Omuto 2008; Haregeweyn et al. 2017). These practices principally affect erosion by modifying the flow pattern, grade, or direction of surface runoff and by reducing the amount and rate of runoff (Renard et al. 1997; Dabral et al. 2008; Karydas et al. 2009). This factor is a ratio between erosion occurring in a field treated with conservation measures and another reference plot without treatment.

The support practices considered in this study for cultivated land includes contour plaguing, strip cropping, bunds, fanyajuu, drainage systems and others. On non-cultivated land, support practices considered includes hillside terraces, check dams and other practices that result in storage of moisture and reduction of runoff. A support practice is most successful when it causes eroded sediments deposited on the upslope, very close to their source than close to the end of the slope (Adugna et al. 2015).

The P-factor map generated tells as the conservation practice carried out in the area. Based on interview of the local community, site observation by transect walk, secondary information collected from District and local agricultural offices the conservation practice in the area is negligible. Hurni et al. (2015) used an approximate expert-based modeling approach to produce a soil and water conservation distribution map for much of Ethiopia including the study watershed. The result shows majority of the area not yet covered by soil and water conservation practices. Studies conducted in Ethiopia by Soil Conservation Research Project have found P values for various support practices and land use cover that ranges between 0 to 1 because of farming practices or soil and water conservation measures (Hurni 1985). With no erosion control practice, P is equal to one. Therefore, values for this factor assigned considering the local management practices and based on values suggested by Hurni (1985) and other similar studies conducted in the area.

Finally, the study watershed divided into different parts based on land use types, land cover practices and support factors. Then P value factor assigned for each of the class according to the following values 0 to water body, 0.5 for forest, 0.63 for settlement and grazing land, and 0.9 for cultivated land. To do that the classified LULC map format has changed into vector format, the corresponding P values assigned to each land use/land cover classes, and the P factor value map produced (Figure 5-8).

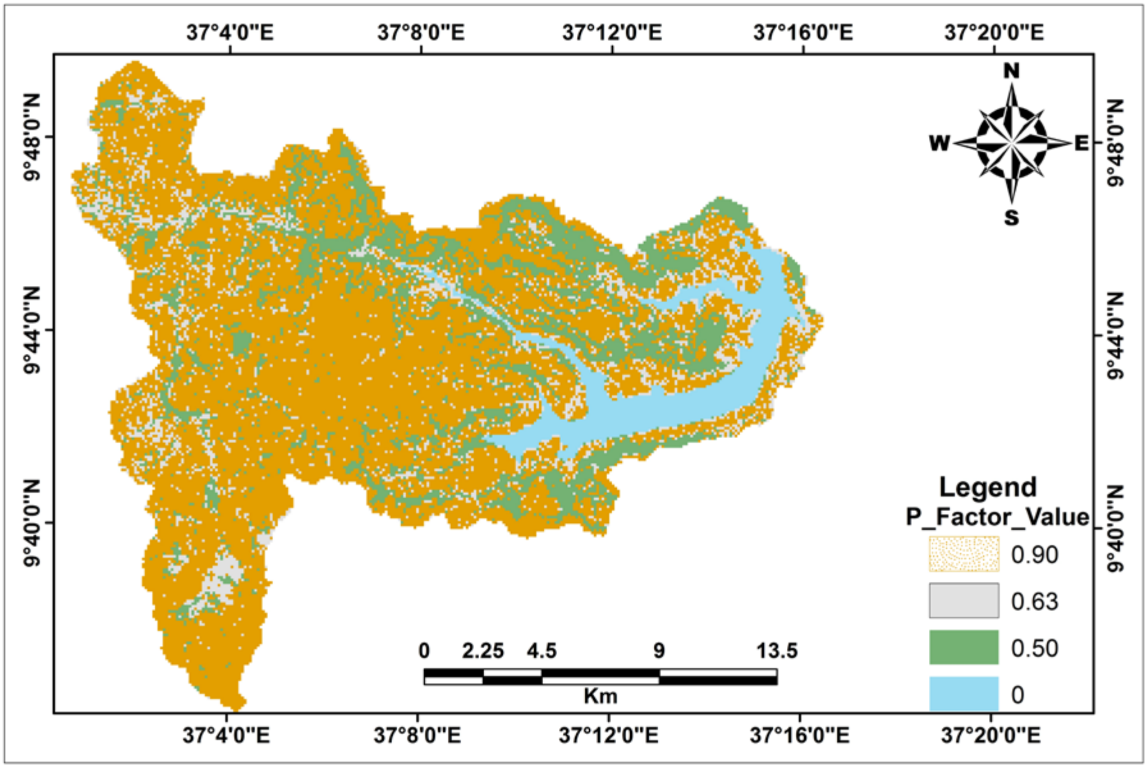


Figure 5-8: P - Factor Value Map

5.4Results and Discussion

5.4.1 Soil Erosion Hazard Determination

The result of the analysis revealed that the total amount of soil loss from the watershed is about 1,252,935 ton per year from 33,376 hectares. The result also illustrated that the potential annual soil loss of the watershed ranges from 0.0 to 350.93 t ha^{-1} yr^{-1} (Figure 5-9). Average annual soil loss for the whole watershed anticipated at 37.54 t ha^{-1} yr^{-1}. The anticipated soil loss results are generally realistic and comparable with the results of other similar studies conducted elsewhere in the country. Adugna et al (2015) obtained an annual soil loss of 65.9 t ha^{-1} yr^{-1} from cropland in study conducted in Northeast Wollega about 30 km northwest of the study area. In another study, Bewket and Teferi (2009) estimated 93 t ha^{-1} yr^{-1} of average annual soil loss for Chemoga watershed of the Blue Nile River Basin of Ethiopia. In the same watershed, Bewket and Sterk (2003) also estimated annual soil loss that range from 18 to 79 t ha^{-1} yr^{-1}.

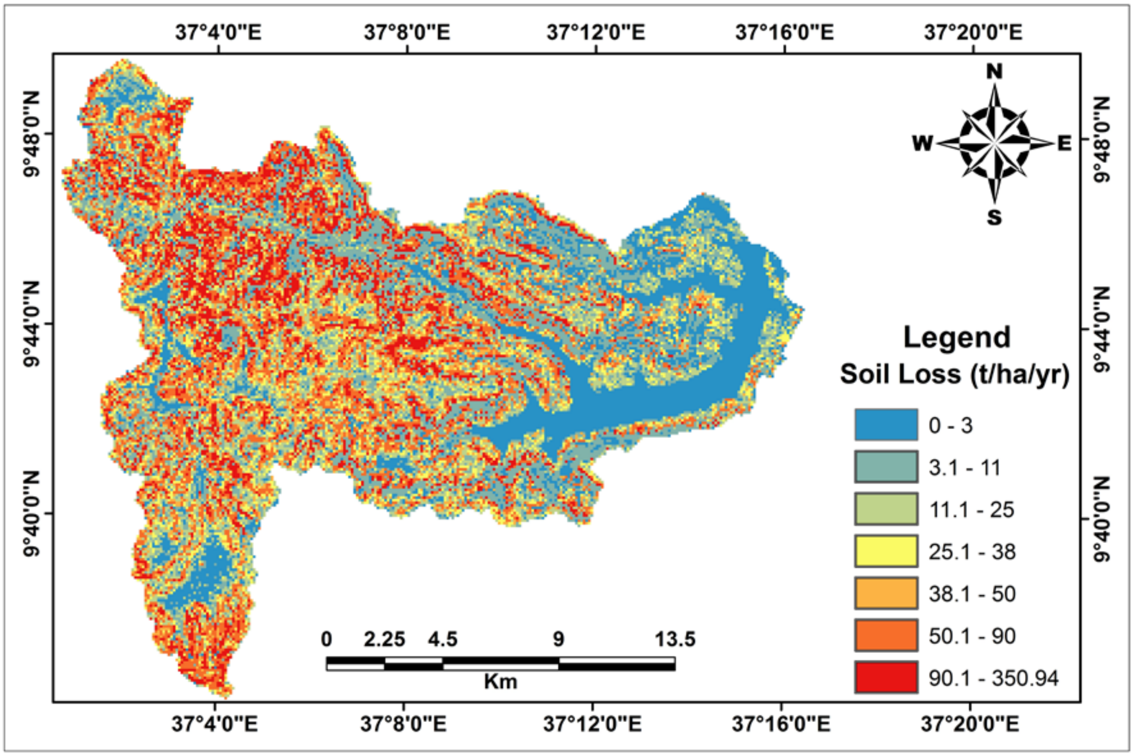


Figure 5-9: Soil Erosion Value Map of the Neshe Dam Watershed

Similarly, FAO (1986) estimated 100 t ha^{-1} yr^{-1} average soil losses from the croplands of the Ethiopian highlands, where the study watershed is located. Likewise, Hurni (1993) estimated that soil loss due to erosion from cultivated fields in Ethiopia amounts to about 42 t ha^{-1} yr^{-1}. Accordingly, Herweg and Ludi (1999) measured 17 - 176 t ha^{-1} yr^{-1} soil erosion rates from traditionally managed cultivated fields in Anjeni experimental micro-watershed conducted for 5 years. Hurni (1985) also estimated the "tolerable" soil loss of about 2-18 t ha^{-1} yr^{-1}. When we compare the estimated average soil loss with the tolerable soil loss amount it is more than double that reveals the severity of the problem in the study watershed. The soil loss rates are also beyond the rate of soil generation or formation of 3-7 t ha^{-1} yr^{-1} (Hurni 1985). The estimated soil loss also enormously higher than the mean global rate of soil loss (15 t ha^{-1} yr^{-1}) and mean rate of soil loss for Africa (9 t ha^{-1} yr^{-1}) (Lulseged and Paul 2008).

The spatial locations of the high erosion hot spot area in the study watershed revealed that the potential soil loss is typically greater along the steeper slope areas. Other high soil erosion areas are associated with current land use condition typically that erosion potential land uses like cultivation lands. The swampy, vegetated and plain areas are less vulnerable to erosion hazards.

5.4.2 Erosion Rate by the sub-watershed

In order to determine which area of the watershed is with high risk of erosion for prioritization of intervention, the study watershed classified into eight sub-watersheds based on their drainage pattern (Figure 5-10). The area of the sub-watersheds ranges between 16.14 Km^2 (sub-watershed D) and 78.78 Km^2 (sub-watershed E). The soil loss values for each of the sub-watershed extracted from the soil loss map of the watershed and mean soil loss value for each sub-watershed presented Table 5-3 below.

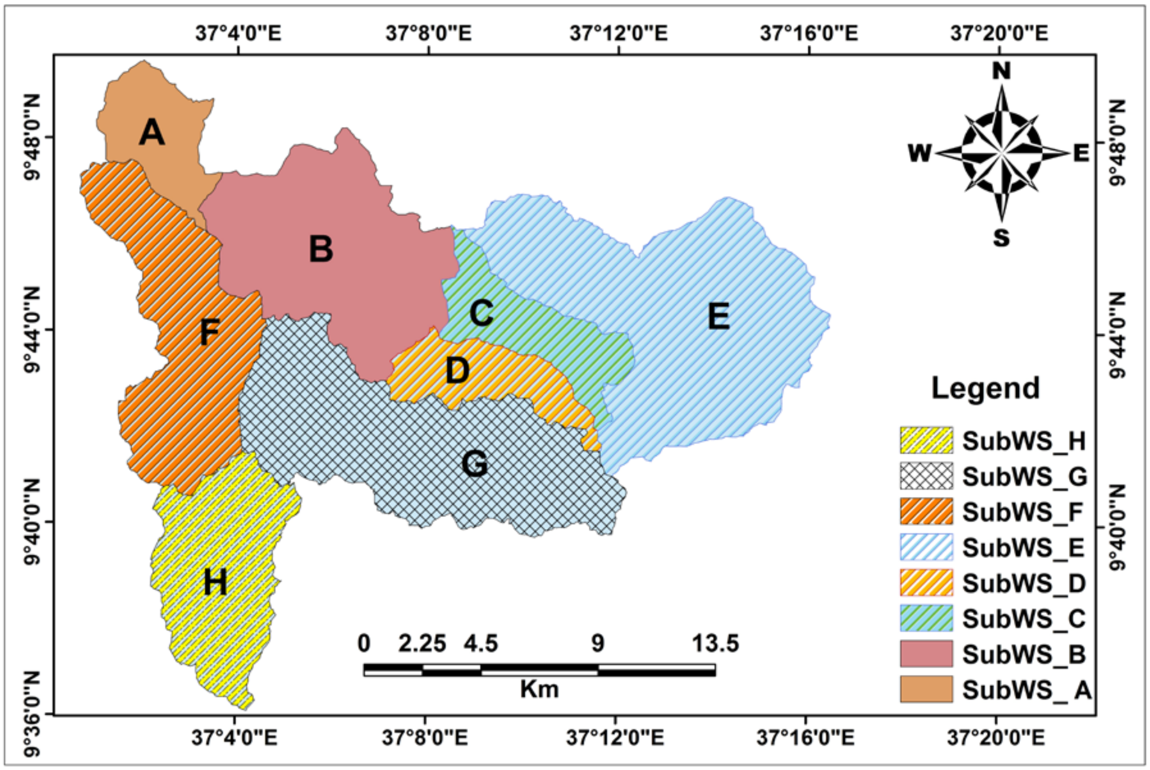


Figure 5-10: Sub-Watersheds of the Neshe Dam Watershed

Of the eight sub-watersheds, five (A, B, D, F & H) were predicted to experience annual soil loss of more than the watershed's average (37.5 t/ ha/yr), whereas three sub-watersheds (C, E & G) estimated annual soil losses were less than the average watershed (Table 5-3).

Table 5-3: Soil Loss from Sub-Watershed

Rank	Sub watershed	Area (Km^2)	Area Percent	Mean Soil Loss (t/ha/yr)	Ranges of Soil lose (t/ha/yr)	Standard Deviation
1	B	54.50	16.3	56.62	0 – 350.93	54.39
2	F	46.19	13.8	47.19	0 – 267.77	43.95
3	A	16.32	4.9	44.36	0 – 247.33	40.23

4	D	16.14	4.8	40.98	0 – 238.28	40.23
5	H	35.31	10.6	40.82	0 – 253.79	38.78
7	G	66.86	20.1	36.86	0 – 286.80	36.95
8	C	19.66	5.9	35.69	0 – 248.28	44.53
9	E	78.78	23.6	16.06	0 – 282.11	26.61
Neshe Dam Watershed		**333.76**	**100**	**37.54**	**0 – 350.93**	**42.56**

5.4.3 Prioritization of Sub-watersheds for Treatment

In this study, prioritization of sub-watersheds done based on average annual soil losses. The classification done based on mean and standard deviation of estimated values of sub-watershed soil losses. Table 5-4 and Figure 5-11 indicate the distribution and severity of soil loss of the eight sub-watersheds of the Neshe Dam watershed. Prioritization of sub-watersheds involves ranking of the different sub-watersheds according to the severity classes by considering the amount of soil loss occurring for treatment.

Table 5-4: Severity Classes and Prioritization of Sub-Watersheds

Soil Loss (t/ha/yr)	Priority Classes	Severity Classes	Sub-watersheds	Area		% of total soil loss
				Km^2	(%)	
45 – 56.62	I	Very High	B & F	100.69	30.2	31.27
37 – 45	II	High	A, D & H	67.77	20.3	26.78
18 - 37	III	Moderate	C & G	86.52	25.9	30.94
< 18	IV	Low	E	78.78	23.6	11.01

The result showed that very high soil loses (45 – 56.62 t/ha/yr) observed in the central western part of the watershed. Out of the eight sub-watersheds, two sub-watersheds (B & F) covering an area of 100.69 Km^2 and which accounts 30.2 % of the total area contributed 31.27 % of the total soil loss. Sub-watersheds A, D, & H covering an area of 67.77 Km^2 and accounts 20.3 % fell under high soil erosion classes (37 – 45 t/ha/yr). The sub-watersheds C, E & G that predicted to experience low to moderate soil loss together cover about 49.5 per cent of the watershed area. Generally, the result showed that the upper part of the watershed characterized by high generation of soil loss.

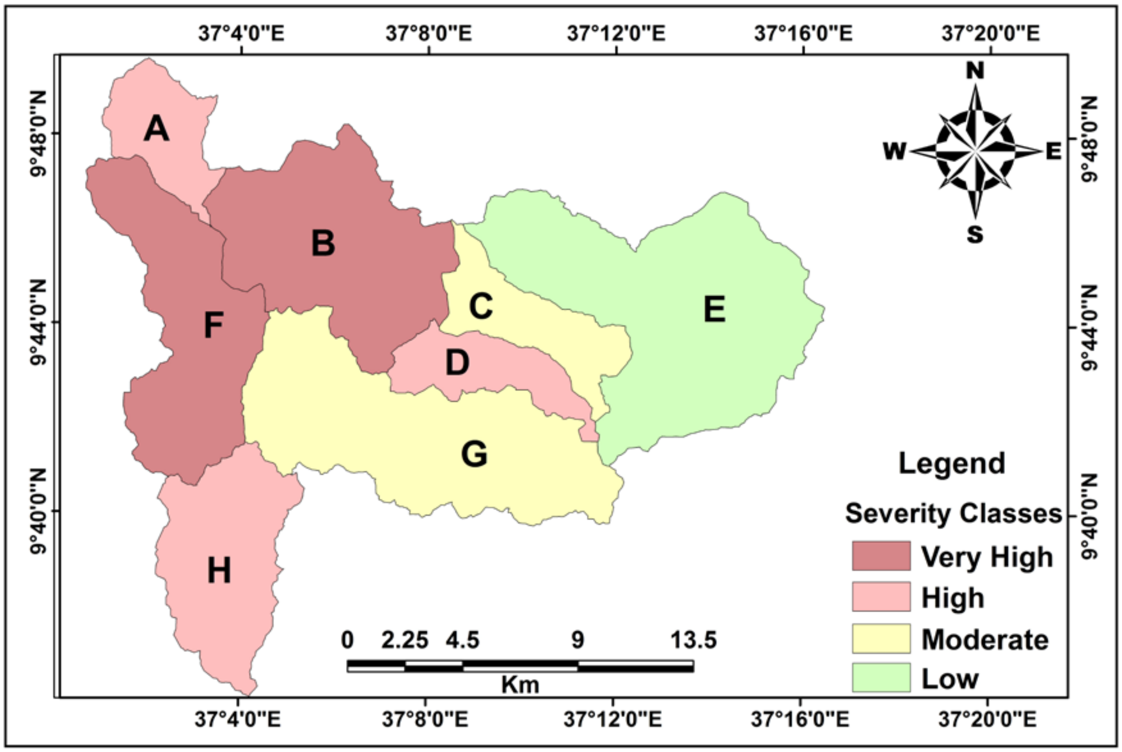


Figure 5-11: Erosion Severity Classes of the Neshe Dam Sub-Watersheds

Based on annual soil losses, those sub-watersheds fell on high and very high erosion classes found to be critical. After ranking the critical sub-watersheds in ascending order, considering the annual soil losses from each sub-watershed, priorities determined (Table 5-4). The sub-watershed ranked at the top in terms of priority class given the top priority for developing the management plan to reduce the soil and nutrient losses. As a result, the critical sub-watersheds ranked and presented on Table 5-4 and recommended to adopt the management measures in order to reduce the soil losses and to conserve the resources within the watershed.

In prioritizing for conservation intervention, sub-watersheds B and F considered in the first stage and sub-watersheds A, D and H regarded in the second stage. The sub-watersheds in the erosion severity class of moderate (C & G) and low (E) can be considered third and fourth for conservation priorities in order of sequence respectively. Connotations such as “very high”, “high”, “moderate”, and “low” are relative terms that reflect the comparison of the sub watersheds among each other.

5.5Conclusion and policy implication

The study demonstrate that an empirically based erosion assessment model, the RUSLE, integrated with satellite remote sensing and geographical information systems can provide useful information for conservation decision-making. It is also apparent that GIS provides a great advantage to analyze multi-layer of data spatially and quantitatively within the watershed. The estimation of soil loss in the watershed using GIS is also in the ranges of other studies. GIS not only provides accurate results but also provides cost and time effective ways of analysis.

The area is an important source of energy for the nation but access to electricity is almost nil in the area. As a result, the community uses dung, crop residue and other sources of biomass as a source of energy. These results in depressed yield of crops and energy generated from the dam by compromising the fertility of the soil and increased siltation of the reservoir.

The average annual soil loss of all sub-watersheds clearly shows that nearly the entire watershed requires implementation of different types of soil and water conservation measures for a sustainable land management. If proper measures not taken now to protect the soil through appropriate soil and water conservation measures, the accelerated erosion-taking place in the watershed jeopardize the agricultural production within the watershed and energy generated from the dam in the long term. Any strategy used for soil and water conservation, must focus upon the changes of the values of the factors taken into consideration in soil loss evaluation. In addition, further study also recommended for determining what conservation measure will be required for each severity classes to halt the situation.

6. SYNTHESIS & POLICY IMPLICATION

6.1Background

Agriculture in the sub basin has practiced as a source of livelihood system almost for the entire population residing in the area since long period time. This may be due to the areas great endowment of natural resources potentials that can greatly contributes to agricultural production and productivity. These potentials include land resources suitable for agricultural production, bio-diversity resources (both in crop and livestock), and agro-ecological resources suitable for the production of numerous crop and livestock types. However, these resources have challenged and is challenging by climate variability and change. Although many factors contribute to the poor performance of the agricultural sector, poor climatic conditions, especially the timely onset, duration, amount & distribution of rainfall, are the main reasons. Furthermore, the past trends of climate variability and change that contributes to the poor performance of agricultural production, expected to sustain in the future. This indicates that the country's in general and the sub basin's in particular agriculture must cope with further warming, changing in amount and pattern of rainfall, and frequent climatic or weather extremes (such as droughts and floods) that caused land degradation.

There is substantial evidence that the climate is changing (Cubasch et al. 2013). Historical greenhouse gas (GHG) emissions have already "committed" the earth to some level of warming (Adger et al. 2007), and the global mean temperature will probably exceed 2 °C against 1900 level over the next decades, regardless of mitigation measures (Parry et al. 2009). Global warming beyond this threshold level (2 °C against 1900 level) is considered to be dangerous, in that this could interfere with the climate system and risk very large impacts on multi-century time scales (Parry et al. 2009; Smith et al. 2009).

Different studies conducted in Ethiopia also revealed that the climate is changing in the country. As mentioned above, there has been an increasing trend of temperature increase over the past decades and projected to continue over the long term (NMA 2007; EPCC 2015). The nation's rainfall characterized by seasonal and inter-annual variability (Kindie et al. 2016; Seleshi and Zanke 2004; Conway 2000). The annual rainfall variability in most part of the country remains above 30% (Kindie et al. 2016). Many of these changes will lead to multiple socio-economic impacts such as altering today's yields, earning, health and physical safety and, ultimately, the paths and levels of future development (World Bank 2010).

Ethiopia frequently cited as a country that is highly vulnerable to climate variability and change (World Bank 2010; Conway and Schipper 2011; EPCC 2015). Historically, Ethiopia is prone to climate-related hazards. The nation's high vulnerability arises first from the heavy dependency of the economy on rain-fed agriculture and the risks associated with rainfall variability.

Under climate variability and change, evidences suggest that changes in rainfall pattern causes relocation of suitable area of production for different crops in Ethiopian agriculture. Evangelista et al. (2013) showed that by 2020 the major cereal crops of Ethiopia such as maize, tef, sorghum and barley will loss over 14, 11, 7 and 31% of their current suitable area of production, respectively. On the same token climate variability and change also affects duration of crop growth by slowing or hastening growth and development processes. Kassie et al. (2014) revealed study conducted on maize in the central Rift Valley of Ethiopia using two crop simulation models under various climate change scenarios predicted a reduction of maize growth duration by 14-33 days in 2050 compared to the present due to higher temperature and variable rainfall conditions. Other impact of climate variability and change on crop include the increase in prevalence and dynamics of crop pests and diseases in Ethiopia (Kindie et al. 2016).

Apart from these, climate variability and change also intensifies the land degradation problem particularly soil erosion in the highland parts of the country in general and study area in particular. Such a problem is a threat to those whose livelihood strongly attached to subsistence agriculture in highland parts of the country. A range of studies have signified that climate change induced land degradation threatened the countries plan of food self-sufficiency and it is also a formidable threat to the livelihoods of smallholder farmers and significantly costing the economy of the nation (FAO 2014).

Finally, even though, the level of awareness at woreda, development agent and farmers' level are minimal in the study sub-basin. The government of Ethiopia also aware of the implication of climate variability and change, and formulated policy and strategy documents like Climate Resilient Green Economy (CRGE) documents in 2011. The document put forward responses carried out in dealing with the impending challenges of climate variability and change.

In the process of the study, the research studied the agroecosystem analysis of Finca'a sub basin; assessed the vulnerability of smallholder farmers to climate variability and change; investigated the perception and adaptation of smallholder farmers; and evaluated the erosion hazard for conservation planning of Neshe Dam Watershed. This chapter presents the synthesis of the main findings and their implication for sustainable agricultural livelihood in the face of climate variability and change.

6.2Agroecosystem Analysis

The agroecosystem analysis revealed that there are four agroecosystems in Fincha'a sub basin. The four identified agroecosystems are the Highland with sloping terrain AES, the Midland with rolling plateau AES, the Wetland with the artificial lakes AES and the Lowland AES. Each of them shows a notable difference in terms of agro-ecological zones, dominant sources of livelihood, production potentials, constraints, and production orientations. The variety of agroecosystem grants both an opportunity and challenge for vulnerability and adaptation strategy to climate variability and change. The multiplicity of climate conditions suggests that variety of farming techniques, growing different crops, and strategies are active within the region, providing a broad foundation for adaptive efforts, but that same diversity makes it difficult to establish climate change projections and adaptation strategies that targeted to address to these highly localized specific conditions.

6.3Vulnerability to Climate Variability and Change

According to the Inter-Governmental Panel on Climate Change (IPCC), vulnerability defined "as a degree to which a system is unable to cope with negative effects of climate change". Vulnerability also expressed in terms of three variables, i.e., exposure, sensitivity and adaptive capacity. The two main drivers of vulnerability are climatic and non-climatic. The climatic drivers of vulnerability associated with major climatic factors influencing agriculture that include rainfall pattern, temperature regimes, and extreme climatic events leading to serious negative consequences for agriculture (drought, food, and frosts).

The main non-climatic drivers of vulnerability in the study area are associated with agricultural land use, demographic pressures, socio-economic and technological factors and poverty issues. Each of these drivers has their own causes and contributes to vulnerability of the agriculture sector. For example, misuse of land through deforestation, overgrazing and inappropriate farming practices results in land degradation, of which soil erosion is classic example. The estimated annual soil loss from inappropriate land management practices in steep slopes could reach as high 350.93 t ha^{-1} yr^{-1} (Figure 5-9). Land exposed to such practices could also result in GHG emissions, according to the CRGE strategy document. These situations also further aggravated by population growth, inadequate socio-economic circumstances leading to poverty and inadequate availability or adoption of improved and more efficient agricultural technologies.

Specifically, the agroecosystem-level vulnerability study analyses the vulnerability of smallholder farmers to climate variability and change based on the integrated vulnerability assessment approach using vulnerability indicators for Fincha'a sub basin. The vulnerability indicators include a series of different socio-economic and biophysical attributes of mixed-crop-livestock farming. The various socio-economic and biophysical indicators have classified into three classes, based on the Intergovernmental Panel on Climate Change's (IPCC 2001) definition of vulnerability, which consists of adaptive capacity, sensitivity and exposure. In the IPCC framework, exposure has an external dimension, whereas both sensitivity and adaptive capacity have an internal dimension, which implicitly assumed in the integrated vulnerability assessment framework (Füssel 2007).

The approach defined eight biophysical and socioeconomic profiles related to vulnerability based on review of literatures that match the conditions and constraints facing smallholder agricultural households in the sub-basin. The profiles include climate, ecosystem, agriculture, wealth, technology, infrastructure, community, and social network. Accordingly, the vulnerability index derived for four Agroecosystems found in the sub-basin. Each profile is composed of several indicators or sub-components. The eight vulnerability profiles then mapped onto the three IPCC contributing factors to vulnerability. Each of the profiles, with the possible exception of climate profile, can also be associated with one of the five types of capital used in the Sustainable Livelihoods Approach.

The result revealed that in Fincha'a sub-basin, exposure is high and adaptive capacity is low for Lowland AES. This results in minimum LVI-IPCC scores, which we classify here as "highly vulnerable" since it indicates an adaptation capacity deficit and high exposure relative to other

AESs. The opposite is true for midland AES, in which adaptive capacity exceeds exposure and overall vulnerability estimated to be low. The highland and wetland AESs exhibit intermediate vulnerability scores.

6.4Adaptation to climate variability and change

There are considerable evidences that the global climate is changing and projections suggest that the rate of change will increase in the future. Climatic parameters like precipitation, temperature, wind, humidity, and sunshine determines largely which crops can grow in an agricultural ecosystem. The challenge for agriculture is to adapt fast enough to a changing climate, and to shift production practices to reduce and preferably mitigate the "carbon footprint" of the food production system.

Accordingly, for someone to take action to adapt to climate change autonomously, he has to recognize climate change first. It is thus important to have some understanding about the perception of climate change by people residing in Fincha'a sub basin. Another important aspect of adaptation is the specific impacts climate variability and change brings on their agriculture and the strategies people use.

With regard to perceptions of climate variability and change, the survey results show that a large number of smallholder farmers have noticed some form of climate change. For example, about 93 % of the total respondents perceived that the temperature has increased; about 89 % claimed that they observed either decreasing or overall change in seasonality of rainfall; 86% experience drought extreme weather event; and 88% experience flooding extreme weather events in the past 20 years.

Farmers' perception of increased temperature is consistent with what reported in the National Adaptation Plan of Action and Ethiopian Panel of Climate Change (EPCC) that the average temperature in the country increased for the last five decades. Conversely, the perceived decline in rainfall does not show decreasing records in many parts of the country rather show variability (NMA 2007; EPCC 2015). KIIs & FGDs unanimously witnessed increasing trends of temperature. Regarding rainfall, the discussants raised different views: all participants agreed the change in rainfall pattern but there are diverse views among the participants in overall amount of rainfall. Some argued total annual amount increased and many others said decreased. The difference is mostly associated with the variation in agroecosystem.

To take action farmers must understand the specific impacts of climate variability and change on the agriculture. Climate variability and change affects crop production mainly through changes in temperature, rainfall, which collectively influence the length of growing period, time of critical growth rate, increased evapo-transpiration and hence seriously reduced and in some cases causes complete crop failure (Mahoo et al. 2013). Though there are variations among AES, more than 85% of farmers had observed decline in length of growing period during the main Kiremt season. With statistically significant differences among the AES, about 41.6% of total respondents reported decline in water availability, while 39% believed that there was more variability in water availability.

The adaptive strategies implemented in agriculture mostly related to technical changes in farming practice. In crop production, it includes: i) using new crop varieties (50.8% of the total respondents), ii) incorporation of crop residue (37.6% of the respondents), iii) adjusting the agricultural calendar/ dates of planting and harvesting (32.9% of the respondents) and iv) use of early maturing crop varieties for the crops traditionally produced (26.6% of the respondents). Measures implemented by farmers in the livestock sub-sector includes: i) sale weak and old animals before the outbreak of long dry season (37.1% of respondents), ii) reducing the number of animals kept (23.4% of respondents), and iii) livestock diversification (14.7% of respondents).

Generally, the adaptation measures implemented until now are not adequate to meet the impending challenges situate by climate variability and change. There is also extrication between farmers' perceptions of climate variability and change, and actual adaptation level. Despite significant number of farmers' perceived changes in temperature and rainfall, the number of farmers adopted certain adaptation measures are below average. The finding also revealed the presence of multiple barriers that impends adaptation efforts. The most important barriers include lack of technical knowledge and climate information/awareness, lack of/ insufficient supply of modern agricultural inputs, shortage of labor, poor potential for irrigation, lack of financial capacity, and lack of technical support (inadequate farmer capacity and training).

Therefore, serious effort has to be made to resolve the barriers that impends adaptation efforts in order to reduce the vulnerability of smallholder's farmers to the changing environment. Several researchers and organizations in Ethiopia have proposed different adaptation options that are thought to reduce agricultural vulnerability to climate variability and change. These adaptation options first compiled, detailed mainly by the National Adaptation Program of Action (NAPA), and later replace by the Ethiopian Program of Adaptation to Climate Change (EPACC). EPACC suggests comprehensive strategies for the success of adaptation in the agriculture sector. However, this particular study revealed lack of guiding principles and limited understanding at Woreda and Kebele levels. A study carried out by the World Bank (2010) proposes increasing irrigated cropland and investment in agricultural research and development as the two pillars of national adaptation strategies in agriculture.

6.5Erosion Hazard Assessment for Prioritized Action

Soil-erosion-induced land degradation is a great challenge in the Ethiopian highlands. Deterioration of crop production particularly in the highlands cited as a major and prime impact of the land degradation, where soil and soil nutrient loss due to erosion is a leading cause (Nyssen et al. 2009). Awulachew et al. (2007) also argue although Ethiopia has huge hydropower and irrigation potential, environmental degradation, particularly erosion and vegetation clearance in the highlands, is threatening this potential. The rationale behind this specific objective is the study conducted by the Nile basin initiative that shows the Fincha'a sub-basin is one of the Land Degradation Hotspot areas within the Abbay River Basin of Ethiopia.

These adverse impacts may become a more considerable problem under the changing environment of the 21st century, since future climate change expected to affect the extent, frequency and magnitude of soil erosion in a number of ways (Pruski and Nearing 2002a). The impacts of climate change on soil erosion can be direct and indirect impacts. The direct impacts caused mainly by changes in the erosive characteristics of rainfall (Pruski and Nearing 2002a; Bangash et al. 2013), and owing to amore vigorous hydrological cycle facilitated by a warmer atmosphere, climate models are projecting that these characteristics will increase in the form of more intense precipitation events over the coming decades (Trenberth et al. 2003; IPCC 2007b).

The indirect impacts related to the rising temperature. A warming climate influences soil erosion mainly through changes in vegetation cover and soil moisture (Nearing et al. 2004).

In addition, a more indirect effect of climate change on soil erosion could occur because of shifting land use and agricultural practice to accommodate the new climatic regime (Williams et al. 1996). Modifications to planting and harvesting dates and the implementation of new crops and complete land use changes are possible, all of which carry the potential to considerably alter rates and patterns of soil erosion (Nearing et al. 2005).

The study demonstrate that an empirically based erosion assessment model, the RUSLE, integrated with satellite remote sensing and geographical information systems can provide useful information for conservation decision-making. The result of the study, the average annual soil loss of all sub-watersheds, clearly shows that nearly the entire watershed requires implementation of different types of soil and water conservation measures for a sustainable land management. Unless proper measures taken now to protect the soil through appropriate soil and water conservation measures, the accelerated erosion-taking place in the watershed jeopardizes the agricultural production within the watershed and energy generated from the dam in the long term. Any strategy used for soil and water conservation, must focus upon the changes of the values of the factors taken into consideration in soil loss evaluation.

Owing the high human population of the area, high population of the livestock, cereal based farming system, land intensive development activities carried out in the area, and climate variability and change induced vulnerability of the area sustainable land management interventions needed badly as a remedial measures. The aim of the interventions is not only in-situ soil conservation but also protection of the hydropower dam against sedimentation. Although agriculture is the major economic sector in the area, it is still traditional and largely based on cereal-livestock farming systems. In the sub basin mixed crop-livestock farming system, have both complimentary and competitive effects to each other.

6.6Study linkage among the different objectives

As it is recalled, the first objective of the dissertation report discussed about the agroecosystem analysis of the Fincha'a sub basin. Based on the analysis the possible agroecosystem found in the sub basin identified and the pattern, productivity and sustainability analysis of each of them discussed in detail. These are the setting for subsequent chapters of the dissertation.

The second objective deals with climate variability and change vulnerability analysis of the agroecosystems. The sub basin's high vulnerability arises first from the heavy dependency of the economy on rain-fed agriculture and the risks associated with rainfall variability. Second due to the low-level of transfer and adoption of improved agricultural technologies and practices required to meet the production needs of the changing environment. Third, the topographical condition that causes severe land degradation problem coupled with the low adaptive capacity to adverse impacts of climate variability and change are some to mention.

The third objective deals with perception and adaptation to climate variability and change. To minimize the impacts and vulnerability of farmers related to climate variability and change, there should be some sort of adaptation mechanism. For a farmer to action to adapt to climate variability and change, he has to recognize the change first. Thus, it is important to have known the perception of the farmers and then the impacts of climate variability and change on their agriculture and the specific adaptation strategies farmers use to halt the situation.

The fourth objective dealt with erosion hazard assessment for prioritized action. Apart from increased average temperature and rainfall variability, climate variability and change causes weather extreme events like drought and flooding. These aggravated the land degradation problem in the form of soil erosion already surfaced in the area. The area is prone to soil erosion due to topographic, soil properties, land cover, climatic, and anthropogenic factors. Therefore, it is cognizant to examine the state of soil erosion and the subsequent sedimentation of the Neshe Dam watershed in the Blue Nile River basin, which is one of the hydroelectric and Irrigation water supply infrastructures of the country.

As climate variability and change increases the land degradation problem in the form of accelerated erosion become severe and severe. The erosion problem in turn minimizes the fertility of the soil because of soil loss from the watershed that has a negative impact on production and productivity of the agricultural fields. As production and productivity compromised, the vulnerability of the community increased. Therefore, it is imperative to study the level of soil erosion, and identifies areas of high erosion loss in the watershed that provide useful incite for conservation decision-making. The action taken to halt the land degradation problem has counter positive impact in minimizing the vulnerability of the community.

Generally, vulnerability depends on the exposure and sensitivity to changes, and on the ability of the system to manage these changes, i.e. on their capacity to adapt (adaptive capacity, adaptability, coping ability) (IPCC 2001). Adaptive capacity on the other hand means the whole of capabilities, resources and institutions of a country or region to implement effective adaptation measures to varied changes. Erosion hazard decreases the productivity of the land and proportionally increases the vulnerability of the farming community. Furthermore, erosion increases the siltation of the hydroelectric dams found in the sub basin. Hence, enhancing resilience increases adaptive capacity (Smith et al. 2003).

In the sub basin, the total annual of rainfall is not a problem; rather the changes associated with rainfall variability, including amount, timing and intensity and its associated droughts and floods causes more vulnerability. Because the variability and change in pattern affects duration of crop growth by slowing or hastening growth and development processes. For example, crops need more water during the development stage, compared to early or late growth stages. The same amounts of annual rainfall during different stages of crop growth have different level of impacts.

In the effort to grapple with the challenge of global climate change, adaptation is unavoidable, as the most restricted measures to reduce the emission of greenhouse gases (GHGs) at this stage would not be sufficient to avoid the impacts of climate change (Berrang-Ford et al. 2011). Therefore, government policies should strengthen the existing adaptation strategies practiced by farmers and support the adoption of adaptation technologies that have the potential to reduce damages at the farm level, such as crop and livestock diversification; the use of drought-tolerant crop varieties and livestock species; water harvesting; irrigation development; research and development, and resource conservation and management practices. Policies that avail information on the type of adaptation methods and provide financial resources to support adaptation should be targeted to ease the constraints to adaptation.

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APPENDICES

Appendix I: Household Survey Questionnaire

Dear Sir/Madam,

This is a survey questionnaire designed to collect data and analyze critically the level of Vulnerability and Adaptation Strategy to Climate variability and Change at Agroecosystem level in Fincha'a sub basin of Horo Guduru Wollega Zone, Oromiya Regional State, as part of a PhD dissertation work. Your responses to each item of the questionnaire are very much crucial for the success of this study. Thus, you are kindly requested to give a genuine answer for each of the questions outlined. Finally, the researcher wants to assure you that your responses will be kept confidential and only used for the above stated purpose.

Thank you in advance for your time and participation.

Name of data collector ______________________Date ____________Code _________
AES: _________________
Wereda: _________________
Kebele: __________________

I. Socioeconomic Characteristics

S.No.	Questions	Response categories
1	House Code	__________________
2	Sex of household head	1. Male 2) Female
3	Age of household head	1= < 15 (child headed family) 2=15-30 3= 31-65 4= >65
4	Marital status of household head	1. Single 2) Married 3) Divorced 4) Widowed
5	Religion of household head	1. Orthodox 2) Muslim 3) Protestant 4) Catholic 5) Wakefetta 6) Others (specify)_____________
6	Ethnic background of the household head	1. Oromo 2) Amhara 3) Gurage 4) Others (specify) _____________
7	Educational status of the household head	1= illiterate 2= capable of reading and writing 3= primary school 4= secondary school or above
8	Responsibility in the community	1= member of the community 2= religious leader 3= coordinator of community development work 4= Kebele Administrator 5= other (specify) ____________
9	What has happened to the size of your household in the last 5-10 years?	1. Increased 2) Decreased 3) Not changed
10	If it has **decreased**, what is the reason?	1. Death 2) Migration 3) Separation/Divorce 4) Marriage 5) Other (specify) ________________
11	Are there members of the house-hold who are engaged in non-farm activities?	1. Yes 2) No
12	If your answer is **yes**, what are the activities they are involved in?	1. Selling local drinks 4) Selling forest products 2. Petty trading 5) Others 3. Making handicrafts

13. Age distribution and sex of members of the household

Sr. No.	Age	Sex (in number)		
		Male	Female	Total
13.1	<14 year			
13.2	15 - 65			
13.3	>65 years			
Total				

Land

S.No.	Questions	Response categories
14	Do you have your own farmland?	1. Yes 2. No
15	If your answer for question No. 14 is yes, what is its size in hectare or (Timad/ Kert)?	• Cultivated land ____________________ • Grass and woodland________________ • Forest land ___________________ • Homestead________________________ • Irrigated Land_____________________ TOTAL _________________
16	Has your farmland size decreased or increased since you started farming?	1. Increased 2) Decreased 3) No change
17	If your response is **decreased**, what is the reason?	1) Shared with children 2) Redistribution of land 3) Abandoned due to decline in quality of land 4) Occupied by water 5) Other (specify) _______________
18	What has happened to your level of crop productivity (Qt/Ha) over the last 5-10 years?	1. Increased 2. Decreased 3. Not changed
19	If it has increased, what do you think are the reasons?	1)Increased soil fertility 2) Strong extension service (improved seed supply, agrochemical use, organic fertilizer) 3) Suitable weather conditions 4) Soil and water conservation practices 5)Other, please specify ________________________
20	If it has **decreased**, what do you think are the reasons?	1) Land degradation 2) Lack of timely input supply 3) Lack of oxen 4) Rainfall variability 5) Drought 6) Pests and Crop diseases 7) Other, (specify) ______________
21	How many years have you been in farming?	______ years
22	Do you have land use right/ownership certificate?	1. Yes 2) No
23	If your answer is yes for question 22, has this caused you to increase your use of conservation management techniques (SWC, terracing, agro forestry, etc.)?	1. Yes 2) No
24	What is the fertility status of your cultivated land?	1) Not fertile 2) Somewhat fertile 3) Fertile 4) Highly fertile
25	What is the slope of your cultivated land?	1) Flat 2) Somewhat hilly 3) Highly sloping 4) Mountainous 5) Other, please specify _______________
26	What type of soil is you cultivated land?	1) Black 2) Brown 3) Red 4) Other (Specify) __________

27. What are you doing to protect land degradation and to increase the productivity of the cultivated land?

Land conservation activities	Individually (1=Yes, 2=No)	In group (communally) (1=Yes, 2=No)
1.		
2.		

3.		
4.		
5.		
6.		
7.		
8.		

Crops

Sr. No.	Questions	Response categories
28	How many hectares did you farm last year?	……………….Hectares
29	What is the size of your land with improved SWC Practices in ha?	…………………Hectares
30	Do you practice crop rotation in your locality?	1. Yes 2) No
31	What are the sequences of crop rotation?	________, ________, ________, _______
32	What cropping patterns do you use in your farmland?	1)Monocropping 2) Mixed cropping 3) Both 4) Other, if any _____________
33	Do you use conservation tillage practices?	1. Yes 2) No

34. What was the type of crop, area of land, production and input used for 2016 production season?

Type of crop produced	Year	Area of Land in hectare	Productivity (Quintals , 100kg)	Utilization of inputs in percent of land area			
				Chemical fertilizer	Natural fertilizer	Improved Crop varieties	Local crop species
	2016						
	2016						
	2016						
	2016						
	2016						
	2016						
	2016						
	2016						
	2016						
	2016						

35. What was the type of crop, area of land, production and input used for the specified year's production season for three major crops?

Type of crop produced	Year	Area of Land in hectare	Productivity (Quintals , 100kg)	Utilization of inputs in percent of land area			
				Chemical fertilizer	Natural fertilizer	Improved Crop varieties	Local crop species
	2015						
	2015						
	2015						
	2014						
	2014						
	2014						
	2013						
	2013						
	2013						
	2012						
	2012						
	2012						

Livestock

36. What type of livestock you own and what are their numbers?			
Type of animal	**Size in number**	**Their feeding source***	**Problems related to fodder**
Ox			
Cow			
Sheep			
Goat			
Horse			
Mule			
Donkey			
Poultry			
Bee colony			
Other			

*Source of fodder 1= own private grazing land 2= communal grazing land 3= crop residue
4= buying fodder 5= other (please specify)…………………………

Sr. No.	Questions	Response categories	
37	What are the main problems you faced in relation to livestock production?	1. Shortage of feed for animals 2. Animal disease 3. Shortage of open space for keeping 4. Lack of better breeds 5. Lack of veterinary services 6. Shortage of water 7. Others (specify) ________________	
38	How much money do you get from the following sources in 2008/09 EC crop year?	**Income sources**	**Amount in Birr**
		1. Livestock and livestock products sale	
		2. Grain sale	
		3. Poultry and its products sale	
		4. Firewood and grass sale	
		5. Charcoal and *kubet* (cow-dung cake) sale	
		6. Local drinks sale	
		7. Petty trading	
		8. Rural credit	
		9. Labor wage	
		10. Sale of sand and stone	
		11. Remittance	
		12. Others (specify) _____________	

Energy Source

1. What are the main energy sources for cooking your food, and what is the percentage of each? Show by marks: (very commonly (xxx), commonly (xx), rare (x), Nil (0)

Type of energy sources	Dry season	Wet season	Coverage (%)
Firewood only			
Cow dung			
Charcoal			
Crop residues			
Electricity			
Electricity and Gas			
Gas only			
Others (specify)			

Sr. No.	Questions	Response categories
2	Where do you get fire wood? Please indicate the percent of your firewood from each category.	____ Communally owned forest ____ Privately owned forest land ____ Naturally grown trees in the farm land ____ Buying fire wood ____ Other, specify_____________
3	Do you use energy efficient stove?	1. Yes 2) No
4	If your answer to Question No. 3 is Yes, which type of stove do you use?	1. Three stone stoves (open fire system) 2. Closed traditional stoves 3. Mirt stoves 4. Biogas 5. Laketch 6) Others (specify) ……………

Infrastructure and Markets

Sr. No.	Questions	Response categories
1	What is the distance between your house and the nearest road to take transport in hours?	______ walking hours
2	What is the distance of your home to the nearest school (how long does it take (hours))?	______ walking hours
3	Do you send your children to the school?	1. Yes 2) No
4	What is the distance to Health services from your home?	______ (km or walking hours)
5	What is the distance to Veterinary services from your home?	______ (km or walking hours)
6	What is the distance to water source from your home?	______ (km or walking hours)
7	What is the distance between your house and the nearest input/output market in hours?	______ (km or walking hours)
8	What type of agriculture output you sell in the market?	______________________________
9	What is the distance to savings and credit institutions?	______ (km or walking hours)
10	Do you have access to credit services whenever you require it?	1. Yes 2) No
11	If your answer is Yes to Q10, what are the sources of your credit access?	1. Individual money lenders 2. Credit associations 3. Relatives/Friends or neighbor 4. Government organization 5. A combination of these ________
12	If the answer is NO to Q10, what is the reason?	1)Have not wanted to, 2) Denied, 3) Other
13	Do you owe a person or an institution more than 500 Birr?	1. Yes 2) No
14	Who are the organizations or the people you owe this money to?	1)Bank/MFI 2) Government 3) Moneylender 4) Family Member 5) Friend or neighbor 6) Equb 7) Iddir 8) Other
15	How much do you owe in total?	
16	What are your total household savings?	
17	Do you have access to Electricity?	1. Yes 2) No
18	Do you have access to Telephone?	1. Yes 2) No
19	Do you have access to piped water?	1. Yes 2) No
20	Do you have access to a radio?	1. Yes 2) No
21	Is there any market linkage for selling your product?	1. Yes 2) No
22	If your answer is No for Q21, how you can establish the market linkage?	

Institutions (Social Capital)

Sr. No.	Questions	Response categories
1	In which of the social organizations, are you belong to?	1) Idir 2) Iqub 3) Jigi/Debo/Wonfel 4) Mahiber 5) None 6) Other (specify) ___________
2	What are the bases to be member of these social organizations?	1. ______________________________ 2. _______________________________ 3. __________________________ _____
3	Are you a member of farmers Cooperatives?	1. Yes 2) No
4	How did you become a member of the Cooperatives?	1. Voluntary base 2. Mandatory base
5	What are the services provided by the farmers' cooperative you belong to?	1. ______________________________ 2. _______________________________ 3. __________________________ _____
6	Did you participate actively to define the governance structure of your Cooperative?	1. Yes 2) No
7	Did you participate actively in the election of the cooperative leadership?	1. Yes 2) No
8	Are the bylaws agreed by the general assembly?	1. Yes 2) No
9	How do you rate the implementation of the bylaws?	1)Very weak, 2) Weak, 3) Fair, 4) Good, 5) Very Good
10	What is the number of no-work days in a month?	_______
11	How do you rate the tradition of working together in the Community?	1)Very weak, 2) Weak, 3) Fair, 4) Good, 5) Very Good

Access to Information:

Sr. No.	Questions	Response categories
1	Is there any agricultural extension service in your locality?	1. Yes 2) No
2	Does the presence of extension services help you to improve productivity and production?	1. Yes 2) No
3	How often do you meet and get advice from the extension agent?	1)Weekly, 2) Once in two weeks, 3) Once in three weeks, 4) Once in a month, 5. _______
4	Do you get important information related to agriculture and market from this information center/source?	1. Yes 2) No
5	What is your source for climate related information?	1) Radio 2) Television 3) Newspaper and magazine 4) Agriculture experts 5) Neighbors 6) Other, please specify ____________________.
6	Have you participated in skill-upgrading training to improve your knowledge about climate change adaptation?	1. Yes 2) No
7	Did the trainings you participated in help your agricultural production?	1)Very little 2) Little 3) Moderate 4) Significant 5) Very significant

Perception and perceived consequences of climate variability/Change

Sr. No.	Questions	Response categories
1	Is the current climate condition the same as it was 20 years ago in your locality?	1. Yes 2) No
2	Have you noticed changes in temperature over the past 20 years?	1. Yes 2) No
3	If your answer is **Yes**, what change have you noticed in daily temperature in the past	1)Increase 2) Decrease 3) No change/constant 4) I don't know 5) Other, please

	20 years?	specify_____________
4	What are the local indicators that show the variability/change in temperature through time in your surroundings?	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 g) Other, please specify_______________________
5	What change have you noticed in rainfall in the past 20 years?	1) Increase 2) Decrease 3) No change 4) Change in the seasons of rainfall 5) Increase in the frequency of drought 6) I don't know 7) Other, please specify_____________
6	What are the local indicators that show the variability/change in rainfall through time in your surrounding?	a) Changes in cropping season b) Changes in crop types c) Changes in productivity d) Other, please specify______________________
7	Have you noticed changes in drought frequency compared to the past 20 years?	1) Yes 2) No
8	If your answer is **Yes**, how frequent drought occurs within the last 20 years?	__________
9	What are the problems you faced due to drought?	1. Complete crop failure 2. Reduced yields 3. Diseases/health problems/sickness has increased 4. Shortage of water both for animals and people 5. Others (specify) _____________________
10	Have you noticed changes in flood occurrence in the past 20 years?	1) Yes 2) No
11	If your answer is **Yes**, how frequent does flood occur?	_________________
12	What kind of problems you encountered due to flooding?	1. Rotting of tuber and roots 2. Increased fungal diseases 3. Reduced yield 4. Soil erosion 5. Reduced farmland 6. Destroyed food stores 7. Destroyed assets (like farm equipment)
13	What has happened to the cold/frost during the summer season?	1) Increased 2) Decreased 3) Not changed
14	What are the major natural disasters you predict will occur from climate variability and change?	1) Drought 2) Flood 3) Salinity 2) Water-logging

Farmers' Perceived Impact of Climate Variability & Change on Agriculture

Sr. No.	Indicator	Response
1	Change in length of growing period	1)Increase 2) Decrease 3) No Change
2	Change in water availability	1)Increase 2) Decrease 3) More variable 4) No change
3	Change in crop disease	1)Increase 2) Decrease 3) No Change
4	Change in crop damage by insects and pests	1)Increase 2) Decrease 3) No Change
5	Change in the problem of weeds	1)Increase 2) Decrease 3) No Change
6	Any shift in suitable growing areas	1)Yes 2) No

7	Change in livestock disease	1)Increase 2) Decrease 3) No Change

II. Issues related to adaptation practices

S. No.	Questions	Response categories		
1	Do you have access to weather forecasts?	1. Yes 2) No		
2	If your answer is **Yes**, from where do you get these weather forecasts?	1. Use traditional knowledge 2. From extension agents 3. From radio/television 4. Other sources (specify) __________________		
3	Is there any program ever been held to boast awareness on climate change, its cause, impacts and adaptation strategies?	1. Yes 2) No		
4	Based on the information you obtained, do you take any adaptation action?	1. Yes 2) No		
5	If your answer is **Yes**, which Adaptation strategies you pursued for crop production to overcome problems of climate variability or change? (**Note**: Put 1 if applied or 2 if not applied the specified strategy).	Adaptation strategies	Applied	Not applied
		1. Crop diversification		
		2. Using new crop variety		
		3. Adjusting date of planting		
		4. Use of early maturing crop varieties		
		5. Use of drought tolerant crop varieties		
		6. Use of disease/pest tolerant crop varieties		
		7. Incorporation of crop residues		
		8. Planting high value fruit trees		
		9. Aid from safety net program		
		10. Others (specify)		
6	What are the major adaptation strategies you pursue related to livestock production to overcome problems of climate variability or change? (**Note**: Put 1 if applied or 2 if not applied the specified strategy).	1. Livestock diversification (Increasing the type of animals kept)		
		2. Changing the type of animals kept		
		3. Reducing the number of animals kept		
		4. Sale weak and old animals before the outbreak of long dry season.		
		5. Keeping improved animals breeds		
		6. Practicing improved animal feed production/planting trees for animal feed		
		7. Moving with animals in search of pasture and water		
		8. Others (specify)		
6	Adaptaion Measures related to Soil and water management measures used in individual farm (**Note**: Put 1 if applied or 2 if not	1. Crop rotation		
		2. Intercropping		
		3. Compost preparation		
		4. Manure heaping		

	applied the specified strategy).	5. Contour plowing		
		6. Irrigation practice		
		7. Soil & Stone bunds		
		8. Water ways/Cut of drain		
		9. Check Dam		
		10. Water harvesting		
		11. Planting trees		
		12. Others (Specify)		
7	Adaptation Measures through water & other natural resource management: community asset creation (**Note**: Put 1 if applied or 2 if not applied the specified strategy).	1. Participating in soil and water conservation with community		
		2. Participating in afforestation/ reforestation with the community techniques		
		Participating in river diversion with the community for irrigation		
		Others (specify)		
8	When do you take adaptation actions?	1. When faced with problems of climate variability 2. With the anticipation of problems of climate variability 3. When informed by others (like DAs, or elders) 4. Others (specify) ___________________________		
9	Do you think the adaptation mechanisms you employed for climate variability and change are successful?	1. Yes 2) No		
10	What do you think are the constraints affecting adaptation to climate variability and change? (**Note**: Put 1 if applicable or 2 if not applicable for specified constraint).	1. Lack of knowledge & Information …………. 2. Lack of access to modern agricultural inputs…….. 3. Lack of technical support ……… 4. Shortage of land ………. 5. Low potential for irrigation ……….. 6. Shortage of labor …….. 7. Lack of finance ……. 8. Other (Specify)		

11. What activities were done by government institutions to cope with local impacts of climate change at your locality?
………
………

12. What activities were done by none government organizations to cope with local impacts of climate change at your locality?
………
………

13. What do you think the right way to adapt (minimize) the impact of climate variability and change in your village?
………
………
………

Appendix II Soil Loss Estimation Model

The equation is given as follows: A = R*K*L*S*C*P

Where: A = Soil loss (tons/ha/year), R = Rainfall erosivity, K = Soil erodibility, L = Slope length, S = Slope gradient, C = Land cover, P = land management

K: Soil Erodibility Factor

Soil Color	Black	Brown	Red	Yellow
K Factor Value	0.15	0.20	0.25	0.30

C: Land Cover Factor

Land Cover	**Factor**	**Land Cover**	**Factor**
Dense forest	0.001	Other forest	0.02
Degraded grass	0.05	Dense grass	0.01
Badland Soft	0.04	Badlands hard	0.05
Ethiopian Tef	0.25	Fallow Hard	0.05
Cereals	0.18	Fallow Ploughed	0.60
Pulses	0.15	Continuous fallow	1.00
Sorghum, Maize	0.10		

P: Management

Land Management	**P Factor**	**Land Management**	**P Factor**
Ploughing up and Down	1.00	Ploughing on contour	0.90
Intercropping	0.80	Dense Intercropping	0.70
Strip Cropping	0.60	Applying Mulch	0.50
Stone Cover (40%)	0.80	Stone Cover (80%)	0.80

Source: Source Hurni (1985), Hellden (1987), Mekuria (2005)

Table showing K factor value based on Soil type (Ermiyas 2007)

No.	Major Soil Type	Soil Color	SCRP estimates of K Value
1	Eutric Fluvisols	Mostly Brown but variable	0.20
2	Eutric Vertisols	Dark grey or Black	0.15
3	Eutric Cambisols	Brown or Dark Brown	0.20
4	Eutric Leptosols	Brown to Yellowish brown	0.20
5	Haplic Alisols	Reddish brown	0.25
6	Haplic Luvisols	Brown/ Reddish brown	0.20
7	Haplic Nitosols	Reddish brown	0.25
8	Chromic Luvisols	Brown/ Reddish brown	0.20
9	Lithic Leptosols	Yellowish brown	0.20
10	Eutric Regosols	Brown	0.20

Table Showing Crop Management (C) Factor Values in Previous Studies

No.	Land Cover/Use Class	Source	C Factor Value
1	Dense forest	Mekuria 2005	0.001
2	Other forest	Mekuria 2005	0.02
3	Scrub land	CGIP 1996	0.02
4	Grass land	CGIP 1996	0.01
5	Dense grass	Hurni 1985	0.01
6	Degraded grass	Hurni 1985	0.05
7	Cropland/ Wooded crop land	CGIP 1996	0.15
8	Cropland tef dominated crop	Hurni 1985	0.25
9	Cropland, cereals/pulses dominated	Hurni 1985	0.15
10	Cropland, wheat/Barley dominated	CGIP 1996	0.15
11	Cropland, Sorghum/Maize dominated	Hurni 1985	0.10
12	Afro-alpine	BCEOM 1998	0.01
13	Open scrubland	CGIP 1996	0.06
14	Bushland	BCEOM 1998	0.10
15	Bareland	BCEOM 1998	0.60

Appendix III: Weather Data

Element: Precipitation/Rainfall (mm)

Name of Station	Elivation	Geogr 1	Geogr 2	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual Total
Shambu	2460	37.121167	9.5712	10.45	14.10	44.04	63.16	191.29	243.67	324.57	275.42	219.05	93.41	36.58	15.42	1531.2
Neshe	2060	37.26833	9.72333	5.00	5.98	37.57	51.36	179.06	281.56	379.69	400.38	315.31	147.98	28.94	9.60	1842.4
Homi	2371	37.241167	9.621333	8.26	8.87	46.16	62.26	177.05	296.23	352.49	318.64	224.31	105.09	24.11	12.78	1636.3
Fincha	2248	37.37033	9.57	10.90	8.13	45.35	76.39	179.43	323.01	376.32	348.14	246.73	123.47	27.78	19.23	1784.9
Embabo	2341	37.546583	9.69108	2.20	5.24	36.58	36.10	210.34	190.08	339.85	371.28	212.38	122.47	34.18	14.35	1575.0
Combolcha	2341	37.472667	9.502333	7.55	6.13	41.02	43.79	159.69	267.59	446.43	365.26	228.41	71.68	45.56	13.34	1696.4
Sub basin Average				7.39	8.07	41.79	55.51	182.81	267.02	369.89	346.52	241.03	110.68	32.86	14.12	1677.7

Element: Maximum Temperature (^{O}C)

Name of Station	Elivation	Geogr 1	Geogr 2	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual Average
Shambu	2460	37.121167	9.5712	24.13	25.62	25.54	25.34	24.25	21.75	19.97	19.86	21.13	21.95	22.91	23.34	23.0
Neshe	2060	37.26833	9.72333	25.90	27.52	26.21	26.86	25.87	24.17	22.04	22.43	23.09	24.97	25.41	25.86	25.0
Fincha	2248	37.37033	9.57	26.80	28.00	28.27	28.24	27.49	25.48	23.26	22.37	23.43	24.51	25.21	25.88	25.7
Embabo	2341	37.546583	9.69108	26.84	27.54	28.50	28.60	26.40	24.62	22.90	21.88	23.60	24.60	24.93	25.40	25.5
Combolcha	2341	37.472667	9.502333	25.38	26.90	26.68	26.78	25.71	24.43	22.63	22.24	22.61	23.77	23.57	24.13	24.6
Sub basin Average				25.81	27.12	27.04	27.16	25.94	24.09	22.16	21.76	22.77	23.96	24.40	24.92	24.8

Element: Minimum Temperature (^{O}C)

Name of Station	Elivation	Geogr 1	Geogr 2	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual Average
Shambu	2460	37.121167	9.5712	11.25	12.34	13.02	13.30	12.91	11.78	11.37	11.32	11.26	10.96	10.69	10.57	11.7
Neshe	2060	37.26833	9.72333	9.36	10.33	12.53	12.17	12.49	12.51	12.48	12.07	11.65	10.51	9.37	8.70	11.2
Fincha	2248	37.37033	9.57	9.92	10.48	10.93	11.26	11.37	10.86	10.60	10.61	10.77	10.16	9.41	9.14	10.5
Embabo	2341	37.546583	9.69108	10.56	11.74	12.95	13.70	13.34	12.70	12.20	11.88	11.66	11.28	10.80	10.95	12.0
Combolcha	2341	37.472667	9.502333	11.91	12.66	13.09	13.58	13.31	12.25	11.91	11.80	11.94	11.36	11.52	10.51	12.2
Sub basin Average				10.60	11.51	12.51	12.80	12.68	12.02	11.71	11.54	11.46	10.85	10.36	9.97	11.5