The Vulnerability of Livelihood to Climate Variability over the Jema Watershed, the Upper Blue Nile River Basin, North-Western Ethiopia

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A Dissertation Submitted to the Center for Environment and 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 2016

Addis Ababa University

This is to certify that the thesis prepared by Mintesinot Azene Taye, entitled: The Vulnerability of Livelihood to Climate Variability over the Upper Blue Nile River Basin, North-Western Ethiopia and submitted in fulfillment of the requirements for the degree of doctor of philosophy in Development Studies (Environment and Development Studies) complies with the regulations of the University and meets the accepted standards with respects to originality and quality.

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Abstract

The Vulnerability of Livelihood to Climate Variability over the Jema watershed, the Upper Blue Nile River Basin, North-Western Ethiopia

Mintesinot Azene Taye, Addis Ababa University, 2016

Standardizing and integrating biophysical and socioeconomic components of livelihood is one of the challenges in vulnerability to climate variability studies. This study investigated the spatial variability in the level of livelihood vulnerability to climate variability from the point of view of three interdependent factors: exposure to climate variability, agroecosystem sensitivity to climate variability, and adaptive capacity. The study was conducted in the four agroecological zones of Jema Watershed, Lake Tana Sub-Basin, Ethiopia. Climate data (rainfall and temperature) were extracted from satellite based reconstructed meteorological observation, and subjected to geospatial analysis using ArcGIS. Focus group discussion was employed to generate data on farmers' perception of climate variability and change. The agroecosystem sensitivity data (soil texture, terrain, land capability class, and land use land cover type, crop and livestock diversity) were collected from field survey and satellite imagery that were subjected to geospatial statistical analysis. The soil sample was collected from farm plots using hand-auger and core-sampler. Land use-land cover was analyzed employing a supervised classification method. Land capability class was evaluated using USDA's land capability classification guideline as a reference. The socioeconomic data were collected from household farmers using structured questionnaire and then analyzed using ANOVA statistics. In all cases, proportionate stratified sampling technique was used. Ultimately, the summary of these results were analyzed by using IPCC's Livelihood Vulnerability Index. Findings indicated that the inter-annual variability of monthly total rainfall decreased towards west of the Sub-Alphine agroecological zone of the watershed though the difference was not statistically significant. The variability of the duration and on-set/off-set of rainy season were higher in the eastern part. In the downstream, Moist Cool agroecological zone, the texture of soil was found to be clayey, and crop and livestock diversity was observed. The size of the cultivable land decreases towards the upstream. The aggregate standardized values of exposure to climate variability, adaptive capacity and agroecosystem sensitivity to climate variability was in the ranges of 0.408 to 0.525, 0.233 to 0.277 and 0.381 to 0.460, respectively, whereas the aggregate standardized value of livelihood vulnerability ranged from 0.052 to 0.126. To conclude, the upstream experienced larger values of exposure to climate variability and agroecosystem sensitivity to climate variability, whereas the downstream was found to have higher adaptive capacity; and the degree of vulnerability decreased towards the downstream. Except adaptive capacity, this spatial variation in vulnerability and its factors among the agroecological zones were explained by a spatial linear trend. Yet, in all cases, the groups' mean difference was not statistically significant. More annual crop cultivation can be enhanced in the downstream, whereas more perennial crop cultivation, livestock rearing, and forestry in the upstream. Off-farm and non-farm adaptation strategies should be enhanced particularly in the upstream. Meanwhile, mal-adaptation practices like encroachment into steep slopes and changing potential cropland into plantation land should be controlled by enhancing bylaws and that could foster the enforcement of scientific land use.

Keywords: agroecological zones, livelihood vulnerability, exposure, sensitivity, adaptive capacity, land use planning

Signed Declaration

This dissertation, my original work, has not been presented for a degree in any other university, and that all the sources of the material used for the thesis have been duly acknowledged.

Mintesinot Azene Taye---------------------------

Acknowledgements

Above anything else, I thank Almighty God for providing me the opportunity to work a crucial phase of my career and an important part of my professional vision, accomplishing a PhD. In my journey to the PhD, I came across various individuals and groups with whom I have many formal, non-formal and informal interactions. These were helpful to enrich my research skills and conceptualizing my research problem. All of the people were have been kind and cooperative, and I remain grateful them. I have many individuals whom I very much like to acknowledge their special roles and contributions in this study. I am especially grateful to my academic supervisor Dr Belay S. Birhanu (the main advisor) who took the lion's share in shaping the overall design of the dissertation. His critical comments and suggestions on the structure and the contents of the dissertation have been very useful. The co-advisors (Dr Yihenew G/Selassie, Dr Benjamin F. Zaitchik and Dr Shimelis G. Setegn) also have played a vital role in refining the structure and content of the dissertation.

I express my thanks to Dr Shimelis G. Setegn and the Department of Environmental and Occupational Health of Florida International University for admitting me as a guest researcher and providing me an office furnished with internet (free academic Journal articles) and other essential accessories at the main campus of FIU. I am grateful to SIDA/Sweden and Post Graduate Dean office of Addis Abba University which sponsored my stay in the USA. I thank once again Dr Benjamin F. Zaitchik for filling the unexpected financial gap I faced during my stay in the USA. Moreover, I thank the College of Development Studies and the Center for Environment and Development Studies of Addis Ababa University which hosted my PhD study, financially supported part of my field work, and facilitating my scholarly visit to USA. I also extend my gratitude to Climate Change

Thematic Research of Addis Ababa University who provided me with the financial support.

My special thanks also goes to my home organization, the Department of Geography and Environmental Studies of Bahir Dar University, which provided me with a scholarship to pursue a PhD study in the regular program and which allowed me to get a GIS and Remote Sensing training, and which supported me financially to conduct part of my filed work. I also like to appreciate the final support of Blue Nile Water Institute and Geo-Spatial Data and Technology Center of Bahir Dar University for providing me financial support to run part of my field work.

I am also grateful to administrators and experts in Mecha, Sekela and Quarit districts, Amhara Regional State, Amhara Regional State Bureau of Agriculture and its Soil Laboratory Center, and Abay Basin Authority. My gratitude also goes to my family, staff in Bahir Dar University and colleagues for their encouragement. I would also like to give due credit to those who contributed a lot by sharing their knowledge and skill, offering materials and moral support, and facilitating the data collection for the study. Last but not least, I acknowledge all whom I did not mention their name but who contributed individually surely had part to contribute either individually or institutionally in the long and challenging scholarly journey the study required. Thank you to all who supported my study. *Hitsan* Danawit, my daughter, I thank you; I understand you sacrificed the time that should have been spent with me at your early childhood. God bless all of you!

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List of Acronyms

ADLI: Agricultural Development Led Industrialization

AEZ: Agroecological Zone

asl: Above Sea Level

ATRF: Annual Total Rainfall

BD: Bulk Density

BPR: Business Process Reengineering

CDM: Clean Development Mechanism

CSA: Central Statistical Agency, Ethiopia

DAP: Diammonium Phosphate

DEM: Digital Elevation Model

DRM: Disaster Risk Management

DRMFSS: Disaster Risk Management and Food Security Sector, Ethiopia

ENSO: El Niño–Southern Oscillation

EQ: Equation

ESRI: Environmental Systems Research Institute

FGD: Focus Group Discussion

GDP: Gross Domestic Product

GHGs: Greenhouse Gases

GO: Governmental Organization

GPS: Global Positioning System

GTP: Growth and Transformation Plan

HDI: Human Development Index

HDs: Households

IPCC: The Intergovernmental Panel on Climate Change

ISRIC: International Soil Reference and Information Center

LCC: Land Capability Class

LCU: Local Crop Unit

LGP: Length of Growing Period

LULC: Land Use Land Cover

LVI: Livelihood Vulnerability Index

Max: Maximum

Meteosat: meteorological satellites

Min: Minimum

MOARD[1]: Ministry of Agriculture, Ethiopia

MODIS: Moderate Resolution Imaging Spectroradiometer

MOEF: Ministry of Environment and Forest, Ethiopia

MOFED: Ministry of Finance and Economic Development, Ethiopia

$MtCO_2e$: Million metric tons of carbon dioxide equivalent

MTmax: Monthly Maximum Temperature

MTmin: Monthly Minimum Temperature

N_2O: **Nitrous oxide**, commonly known as **laughing gas**

NASA: National Aeronautics and Space Administration

NB: Note Carefully

NGO: Non-Governmental Organization

NMA: National Meteorological Agency, Ethiopia

[1]In this document, the ministry of Agriculture (MoA) is used synonymously with the Ministry of Agriculture and Rural Development (MoARD).

NMSA: National Mission for Sustainable Agriculture

NOAA: **National Oceanic and Atmospheric Administration**

OLS: Ordinary Least Square

PASDEP: A Plan for Accelerated and Sustained Development to End Poverty

PCI: Per Capita Income

REDD: Reducing Emissions from Deforestation and Forest Degradation

RF: Rainfall

RSNDP: Productive Safety Net Development Program

SD: Standard Deviation

SDPRP: Sustainable Development and Poverty Reduction Program

SLM: Sustainable Land Management

SPSS: Statistical Package for the Social Sciences

SQ: Structured Questionnaire

SRTM: Shuttle Radar Topography Mission

Temp: Temperature

TLU: Tropical Livestock Unit

UN/ISDR: The United Nations International Strategy for Disaster Reduction

UNEP: The United Nations Environmental Program

USGS: United States Geological Survey

UTM: Universal Transverse Mercator

WBISPP: Woody Biomass Inventory and Strategic Planning Project

WFP: World Food Program

WGAZ: West Gojam Administrative Zone

WLS: Weighted Least Squares

WOCAT: World Overview of Conservation Approaches and Technologies

Z: Zone

List of Unit of Measurements and Symbols

cm: Centimeter

^{0}C: Degree Centigrade

^{0}E : Degree of longitude (Easting)

^{0}N : Degree of latitude (Northing)

Birr: Local currency

ha: Hectare

Kadda: 1 kadda of land is equal to one fourth of a hectare of land

kg: Kilogram

Km: Kilometer
km^2: Kilometer Square

K: Kappa Coefficient

m: Meter

mm: Millimeter

P-value: Probability Value

%: Percentage

r: Resolution

R^2 = R-Squared (The Square of Correlation Coefficient)

t/m^3: Tone per Cubic Meters

Chapter One

1. Introduction

This chapter begins with a section that describes background of the study as part of introducing the overall context of the study. It focuses on highlighting the Ethiopian economy, possible reasons behind the sluggish pace of economic development, and a snap shot of the current national development policies and strategies. This is followed by a section that states the problem of the study. It focuses on describing the prevalent socio-economic and biophysical situation of the study site, previous experiences in a spatial variation in livelihood vulnerability to climate change and variability, livelihood vulnerability, watershed, agroecological zone (AEZ). Following this the gaps and justification for choosing the study topic are discussed and the output and possible contribution of the study are described. Next, the research questions and the objectives of the study are presented. Finally, the chapter ends with a section that presents the overall organization of the dissertation.

1.1 Background

In this era of rapid climate change and variability (Solomon, 2007), the world is witnessing diverse biophysical and socio-economic dynamism and challenges emerging from it (FAO, 2007). Studies, for example UN/ISDR (2011) showed that economic losses from disasters have reached one trillion US dollars worldwide since 2000. On the other hand, about 95% of humanitarian finance is still spent in the form of relief rather than for prevention and mitigation (Kellett and Sweeney, 2011). This situation was much more pronounced in developing economies including Ethiopia.

The task of identifying and explaining these constraints is rather incomplete and fragmented (Todaro and Smith, 2012). This task has been more challenging in Sub-Saharan Africa, where the majority of livelihoods directly depend on agriculture (World Bank, 2010). The misuse and degradation of land in the Sub-Saharan Africa is aggravated by the negative impacts of climate change and variability-leading which in turn led to decreased availability of natural resources, to a decline in productivity, to an increase in livelihood vulnerability (WOCAT, 2011).

In Ethiopia, about 85% of the population is directly dependent on agricultural production. Crop production, livestock rearing and forestry are the quite vulnerable to the negative impacts of climate change. And yet, these economic activities play a major role in the country's economy, contributing 43% of GDP, about 80% of employment, and approximately 75% of export (MOEF, 2011). Farming in Ethiopia has mainly been mixed (crop-and-livestock based) and subsistence oriented (MOARD[2], 2010). About 80% of population of the country lives in the highlands (CSA, 2008). More importantly, according to the Ethiopian Ministry of Agriculture (MOARD, 2010), agricultural land use is not practiced in line with the scientific Land Capability Class (LCC) guideline. For instance, steep slopes and wetlands have been used for cultivating annual crops. Consequently, soil erosion and water scarcity emerged as major problems of agriculture in the country (Setegn et al., 2009; Waktola, 1999; Hurni et al., 2005). It is estimated that the average rate of soil erosion is about 10 times the rate of soil regeneration in the highlands of Ethiopia (Hurni,

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[2] In some documents, the Ministry of Agriculture (MoA) may be named as the Ministry of Agriculture and Rural Development (MoARD).

1988). The rate of soil nutrient depletion is highest in sub-Saharan Africa. On average, soil is eroded at a rate of 42 tones/ha/year. There are farm fields that lose soil at a rate of 300 tons/ha/year (Hurni, 1998). Environmental degradation and related problems have been more serious mainly in the northern part of the country. As indicated in the report of Jahn (2006), the mean per capita grain production ranged between of 162 kg per year in bad years and 225 kg per year in good years, which indicates that grain yield was below the amount needed to meet the annual grain requirements of about 200 kg per person to be food self-sufficient (De Graaff et al., 2001).

The prevalent low development status of the country has been attributed to the direct dependence of the economy on rainfed agriculture (MOARD, 2010). IPCC (2007) explained that heavy dependence on rainfed agriculture made the livelihood of African farmers more vulnerable to climate change, variability and hazards. The situation has been aggravated by inadequate farming technology; soil degradation caused by rugged terrain and inappropriate land use (Setegn et al., 2009; Selassie and Ayana , 2013; Zaitchik, et al., 2012); poor complementary services such as agricultural extension services, access to credit, market, infrastructure (Endeshaw, 2014); and incompetent institutional and administrative setup (Degefa, 2005; Forsyth, 2004; Mesfin, 1984).

It is projected that by the 2050s, 350–600 million Africans would be at risk (Arnell, 2004; Solomon, 2007), if the institutional setup is not readjusted to be responsive to climate variability and its associated hazards. Similarly, Fields (2005) warned that the convergence of multiple stressors, such as infectious diseases, economic turbulence due to globalization, and civil unrest coupled with the prevalent poor adaptive capacity worsen the degree of livelihood vulnerability to climatic calamities. In Ethiopia, the future impacts could cost up to 10% of GDP by 2050, which could hamper the country's economic growth ambitions, and disproportionately affect most vulnerable populations (MOEF, 2011). Ultimately, people would face severe shortage of food, water, fiber, energy, and other essential goods and services of the ecosystem. As stated in the works of Solomon (2007), Mearns and Norton (2010), due to variation in livelihood assets, the impact of the calamities is expected to vary among and with in countries and societies situated in Sub-Saharan region of Africa. Ethiopia is a nation where greater diversity is noticed with respect to its biophysical environment, socio-cultural practices, and livelihood (Mesfin, 1984; MOARD, 2010). This diversity has been reflected in the spatial (geography) and temporal variations of livelihood vulnerability to drought and famine among the rural communities in the country (Degefa, 2005; Mesfin 1984).

Pankhurst (1985) noted that the most severe famines in the 20th century in Ethiopia were the Tigray famine in 1958, the Wag-Lasta famine in 1966, and the other famine that occurred from 1972–1974 and from 1984-85. According to WFP and FAO's (2016) report, severe hunger and livelihood crisis recurred in 2015/16 immediately after the occurrence of drought caused by El Niño Southern Oscillation (ENSO) phenomenon. A study by Seleshi and Zanke (2004) indicated that previous climate variability over Ethiopia was also linked to the same climate hazard. Historically, this hazard has been occurring in the northern part of the country.

In the last four decades, interests and movements for enhancing sustainable land use and adaptive agriculture have been initiated in various ways across the world. The emergence of development institutions like IPCC, UNEP, and UN/ISDR are among the major manifestations of the initiative. Thus, at the policing level, the Ethiopian government has reached at consensus to exercise green economy parallel to the broader national development agenda as part of packages to address the environmental problem (Agriculture Development Led Industrialization, ADLI) (MOEF, 2011). The policy has been operationalized since the mid 1990s. It focuses on all the activities of agriculture and industries that use agricultural outputs as a raw material. ADLI has initiatives aimed at modernization. In the short run, it focuses on transforming agriculture through intensification and utilization of contemporary technologies and modernization of ‘backward’ practices. In the long run, the policy aims at industrialization (MOFED, 2002). Looking at the contents of ADLI, one can clearly notice an intention to simulate an evolutionary growth model in the country’s economic development plan (Degefa, 2005). The Model has five stages of growth, i.e., the traditional society, the pre take-off, the take-off, the road to maturity, and the mass consumption stages (Rostow, 1960).

ADLI has not been immune from criticism. Yohannes (2016) noted that the national development policy heavily relied on sluggish small-scale peasant agriculture with idealistic premises. Since 1991, the country has become land-locked and relies on the port of neighboring countries for its imports and exports. This has created more constraints to the development of the agricultural sector in terms of increases in the price of vital agricultural inputs such as fertilizers, improved seeds, and pesticides. The aforementioned observations prompt researchers to give attention to embark on development oriented research activities that involve exploring socio-economic and biophysical livelihood profiles.

1.2 Statement of the Problem and Justification

The agricultural land use and conservation practice in the river basin where the current study is situated has not been backed by scientific procedures (Amsalu, 2006; Bewket, 2003; Simane, et al., 2013). The physical soil and water conservation activities have been in practice in the site long before the introduction of Productive Safety Net Development Program (PSNDP) (BOFED, 2012). Efforts made thus far have been fragmented as the main actors have no visualization of implementational framework towards an integrated development of a resilient agriculture system. The broader region of the Blue Nile River Basin has been familiar for being a place where natural resources conservation and utilization is practiced in a disintegrated fashion (Mengistu, 2014; Yitaferu, 2007). Political administrative boundaries rather than watershed and river basin boundaries like Administrative Region, Zone and district (*wereda*) have been used as a spatial framework for the farming system and for development planning (Bewket, 2003; Simane, et al., 2014). Furthermore, there has not been adequate scientific data on the major components of farming system to be used for planning at watershed scale. In another respect, in the GTP (from 2010 to 2025) of the country, gross domestic product (GDP) is projected to increase by 10% each year, with the highest agricultural growth being (9%) and the highest export growth driven by crop and livestock production (MOARD, 2014).

As part of achieving the goal, communities in the study site are expected to utilize their agroecosystem in a way that ensures their comparative advantage. In practice, however, misuse of land and deterioration of livelihood assets is rampant. The problem is manifested in the rapid expansion of bare land (Teferi et al., 2016), gullies, siltation, and shortage of soil moisture (Setegn et al., 2009), and soil nutrient depletion (Selassie et al., 2015). According to Colick et al. (2010), in Lake Tana Sub-Basin, the estimated erosion rate ranges from high severity (> 400 tons per hectare per year (tons per ha^{-1} per year^{-1}) to low severity (< 3.125 tons per ha^{-1} per year^{-1}). As a result, agriculture has not been adequately meeting the current demand for more productivity (Endeshaw, 2010; Simane, et al., 2013). Consequently, farmers have been encroaching into sensitive land classes for grazing, for cultivation and for settlement (Colick et al., 2010). Moreover, they have been compelled to engage in temporary and permanent migrations. This is happening in a situation where the population of the area (West Gojam Administrative Zone) shows an increment with a total average growth rate of 3% per year. The average family size of this area was estimated to be 4.39 (CSA, 2008).

The situation has been aggravated by climate change and variability (Solomon, 2007; Zaitchik, et al., 2012). According to a report by NMSA (2000), over the past 50 years, the mean annual minimum and maximum temperature across the country has increased by about 0.25^{0}C and about 0.1^{0}C, respectively, per decade. By contrast, precipitation has shown a decreasing trend. These trends were predicted to continue in the tropics, including Ethiopia (Solomon, 2007: Mitchell and Tanner 2006). Furthermore, according to studies (Conway and Schipper, 2011: MsSWeeney et al., 2010a), Ethiopia is identified to be highly vulnerable to climate change and variability.

Climate change and variability disasters have been taking place at a regional rather than at a community level (Sheffield and Wood, 2008). An aggregated regional and national study (statistic) could not capture the complex distribution of livelihood vulnerability particularly in the north-western highland region of the country

(Simane, et al., 2014; Zaitchik, et al., 2012). A dramatic spatial heterogeneity is observed in soil features (Hurni, 1998), in steepness of slope (Zaitchik, et al., 2012), in social capital and in access to infrastructure and agricultural technologies (Bamlku, 2010; Simane, et al., 2010). Overall, previous empirical studies conducted in Ethiopia (Endeshaw, 2014; Simane et al., 2014; Degefa, 2005) indicated that spatial variation led to differences in the degree of livelihood vulnerability to climate variability among adjacent localities. Directly or indirectly, the studies indicated above showed the presence of differences in adaptive capacity, in exposure, and in sensitivity to climate variability at a community level. This study is, hence, intended to conduct investigation in the vulnerability of livelihood to climate variability at a larger geographical scale, i.e., among the AEZs of the Jema watershed.

To be able to see the relative relevance for this study, it helps to reflect on the similarities and differences between this and previous studies conducted on the issue. Much like a few previous researches conducted in Ethiopia (Conway, 2011; Simane, et al., 2014; Deressa et al., 2009), this study makes an investigation into relevant socio-economic and biophysical profiles in an integrated manner. Wealth, infrastructure, technology, social capital, climate variability, agriculture and ecosystem sensitivity to climate variability are the components integral to the analysis. Accordingly, an integrated or livelihood approach to vulnerability analysis that is similar in many respects to studies by Hahn (2009), Scoones (1998) and Simane, et al. (2014) is customized to fit the context of the current study site.

Unlike local researches conducted on livelihood vulnerability to climate variability, this study involves and integrates more indicators. Together with spatial variation in agroecosystem sensitivity to climate variability, land use land cover (LULC) type, and LCC are addressed. Moreover, in analyzing spatial differences in exposure to climate variability, variability in onset and end datesof rainy season and duration of rainy season were taken in to account. To manage the study, multiple data sources, multiple research methods and tools were employed.

Unlike most previous livelihood and vulnerability studies in Ethiopia, in this study, AEZ and watershed are used as a spatial framework for analysis. Endeshaw (2014), Deressa et al. (2009), and Simane, et al. (2014) made studies based on a similar framework. In some previous studies (Amsalu, 2006; Bewket, 2003), watershed was used as a geographic unit of analysis. Watershed based studies contributed to an improvement in a comprehensive integrated approach to the management of natural resources. Such studies allowed integration of socio-economic resources with natural resource within the ecosystem (Desta, et al., 2005; Gregersen et al., 1996; Kramer et al., 1997). As environmental entities are interdependent, employing an agroecosystem approach is a commendable scientific way out. Such an approach is more appropriate in situations where climatic and socio-economic dynamics are prevalent (Brouwer and Jansen, 1989; Simane, et al., 2014; FAO, 2007; Gurtner, et al. 2011). In larger spatial scale studies, different agroecosystem features would be reflected in the AEZs of a watershed (MOARD, 2010; Endeshaw, 2014). Hence, the selected geographical scale explains better the spatial distribution of biophysical and socio-economic resources to capitalize regional economies of scale.

As an output from this study, information on factors (exposure, adaptive capacity and sensitivity to climate variability) of livelihood vulnerability to climate variability across the AEZs of Jema watershed is expected. The significance (outcome) of this study could be explained in terms of two major perspectives: 1) To the academic community, it enriches the process of knowledge contextualization through integrating a given local context with advanced research tools. Assefa and Bork (2014) stated that land use planners and environmental managers need to consider local knowledge[3] and innovation for achieving a sustainable land management. In the mean time, one may identify and integrate additional environmental variable to the analytical framework of livelihood vulnerability studies that were organized previously. 2) This kind of research is expected to produce more relevant information that could enhance the process of facilitation and implementation of appropriate adaptation strategies. To the local disaster risk management unit and sustainable land use planners, the output helps identify the degree of livelihood vulnerability among the AEZs, and prioritize their comparative advantages and constraints. This would enable to choose and develop more appropriate mitigation, adaptation and coping mechanisms, and to develop a resilient agroecosystem with less degree of vulnerability.

Such information is essential in the context an economic system that heavily depends on agriculture in particular crop production. As stated by MOEF (2011), agricultural crops make up 67% of agricultural GDP (27% of total GDP) of the country. The main crops are cereals, pulses, coffee, oil seeds, spices, herbs, vegetables, flowers, fruits, sugar cane and fiber. Because of the existence of diversified agroecological zones, all the major cereal crops and some others have been cultivated widely across the Jema watershed.

[3] Local knowledge refers to knowledge that people in a given community have developed through experience, and continue to develop, and adapted to local environment and dynamics (IIRR, 1996).

Kelly and Adger (2000), Mohan (2010), Yohannes (2014) explained that mapping vulnerability was an integral for successful adaptation planning, because it helps exchange of experiences and technologies across communities with similar vulnerability profiles. It is much more important in countries where the biophysical and socio-cultural diversity are evident (MOARD, 2010).

The country has identified 41 promising adaptation strategies that could be applicable to various sectors in most of the 14 adaptation planning zones (Annex 2.1) created from the 32 AEZs of the country (MOEF, 2011). And yet, the level of relative priority would vary, and individual sub-options would differ as per the nature of risks and livelihoods to be explored. This implies the need to generate specific livelihood vulnerability profiles to various watersheds and AEZs of the country. MOEF (2014), MOFED (2006), Hahn (2009) and (UN/ISDR, 2007) recognized that the output of such study could be used by organizations working on disaster risk management, natural resources management, environment and sustainable land use planning, agricultural extension, health, education and other development sectors.

In addition, the researcher of this investigation considers the multi attribute analysis of this study as an opportunity to learn on how to integrate, contextualize and apply diversified research materials and methods to the study site. Satellite image and geostatistical analysis, climate data analysis, soil and socio-economic survey and analysis, and focus group discussion (FGD) were employed for characterizing, classifying and analyzing critical profiles of livelihood vulnerability to climate variability.

The Jema watershed is selected as the study site for various reasons. Firstly, the site is one of the recharge zones of the Blue Nile River Basin (DEM 30m r). From the perspective of sustainable river basin management, it is reasonable to begin implementing a proper resource use and conservation at the most upper parts of the basin (Desta et al., 2005; Gregersen et al., 1996). This is because its multiple impacts go to the livelihood of a number of downstream communities of the basin (Johnston, 2010; Wolf, 1999). Moreover, the administrative bodies situated in the watershed do not have a watershed and AEZ based scientific information that is an essential input for productive and sustainable land use (Endesahw, 2006; Yitaferu, 2007; Zone Agriculture Office, 2010). The topic *"livelihood vulnerability to climate change and variability"* has never been studied specifically in the watershed. What is more, there is no an unavoidable barrier to collect both socio-economic and agroecosystem data. Finally, since the watershed consists of multiple AEZs (as it can be observed from DEM[4] 30m r), it could give a picture of the general socio-economic and biophysical attributes of north-western highlands of the country. This research is designed in line with the arguments of Bewket (2003), Conway (2011), Endeshaw (2014) and Simane (2014).
In view of multiple rationales pointed out above, spatial analysis of livelihood vulnerability to climate variability among the agroecological zones (AEZs) of Jema watershed merits a comprehensive scientific study. Against the problem statement and its justifications discussed above, six research questions were set for this study:

[4] DEM 30m r (Digital Elevation Model with 30 meter resolution) is provided by the NASA Shuttle Radar Topographic Mission (SRTM). This imagery is currently available free of charge at the National Map Seamless Data Distribution System, or the USGS ftp website.

1. Is there a spatio-temporal variability of climate among the AEZs of the Jema watershed?
2. Is there a spatial variability of soil among the AEZs of the watershed?
3. Is there a spatial difference in the proportion of land capability class among the AEZs?
4. Is there a spatial difference in the proportion of land use land cover types among the AEZs?
5. Is there a spatial variability in adaptive capacity of farmers' to climate variability among the AEZs? and
6. Is there a spatial difference in vulnerability to climate variability among the AEZs?

1.3 Objectives of the Study

In view of the research questions noted above, the general and specific objectives are defined and presented in the next section of the chapter.

1.3.1 General Objective

The general objective of the study is to examine the biophysical and socio-economic patterns and the degree of livelihood vulnerability to climate variability[5] among the agroecological zones (AEZs) of the Jema watershed, Upper Blue Nile River Basin.

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5 In this study, the concept climate variability is used adopting IPCC's explanation "climate variability constitutes an important component of a system's exposure to climatic stimuli. Global climate change is superimposed on, and is substantially affect, existing climate variability, including the frequency, intensity, and location of extreme events."

1.3.2 Specific Objectives

In the view of the general objective, five specific objectives of the investigation are identified and presented as follows:

1. to analyze climate variability among the AEZs of the Jema watershed;
2. to characterize soil texture among the AEZs of the watershed;
3. to analyze the proportion of land capability class among the AEZs of the watershed;
4. to analyze the proportion of land use land cover type among the AEZs of the watershed;
5. to examine farmers' adaptive capacity among the AEZs of the watershed; and
6. to investigate the degree of livelihood vulnerability to climate variability among the AEZs of the Jema Watershed.

1.4 Organization of the Dissertation

The content of this study is organized under five chapters. The first chapter introduces the study. The second chapter reviews the theoretical and conceptual frameworks employed to govern the investigation. The research materials and methods are explained in the third chapter. In chapter four, the analysis and discussion on the variability of climate, soil texture, land capability class, land use-land cover, farmers' adaptive capacity, and livelihood vulnerability to climate variability among the AEZs of the Jema watershed are provided, and the observed adaptation strategies are discussed. The output of soil texture, land capability class, and land use-land cover are ultimately used for the analysis of agroecosystem sensitivity to climate variability and placed next to the analysis and discussion of land use land cover type. The inter-linkage among these objectives (profiles and factors of livelihood vulnerability to climate variability) is presented as part of analytical framework of the study (Figure 2.3). Chapter five concludes the study. Recommendations and the future research areas are also presented in the last chapter.

Chapter Two

2. Literature Review

This chapter starts by indicating the source of RF bearing winds to Ethiopia, and proceeds to highlighting the leading thought with regard to causes of the current climate change. Following this, development-research paradigms are presented and evolution of vulnerability assessment framework is discussed. Next, fundamental concepts employed for investigating the questions of this study are presented. The chapter concludes by illustrating the analytical framework employed in this study. It is believed that the contents discussed in this chapter would help to make a sound review of research and theoretical literature, and contextualize the main concepts as well as prior research practices and methods that have practical implications for the current study.

2.1 Climate Change and Variability

The spatial pattern of Ethiopian RF follows the direction of rain bearing wind (Griffiths, 1972; Levin, et al., 2009) and topographic variation (Levin, et al., 2009; MOARD, 2000). The moist easterly winds from the South Atlantic Ocean produce the main rainy season during summer season to the Ethiopian Highlands, whereas the most southeasterly winds from the Indian Ocean produce spring rainy season to the same place (Seleshi and Zanke, 2004). Moreover, a cool tropical Indian Ocean has a tendency to be associated with enhanced *Kiremt* rainfall over the north-west and central Ethiopian highlands, and with reduced rainfall conditions over the semiarid lowlands of north-eastern, eastern, southern, and south-western part of Ethiopia (Seleshi and Zanke, 2004).

As indicated in the report of IPCC (2007), the global mean surface temperature increased by about 0.74^0C over the last century; and years of 2000 to 2010 was the warmest decade. A study by Mengistu, et al. (2014) conducted in the Blue Nile River Basin where the Jema watershed is situated showed that at the annual scale, maximum and minimum temperatures significantly increased in over 33% of the basin at a rate of 0.1 and 0.15 ◦C per decade, respectively.

The atmospheric warming registered since the mid-20^{th} century as a result of increase of green house gases (GHGs) is supported observationally by the spatial and seasonal characteristics of global temperature variations. The IPCC fourth assessment report (Solomon, 2007) indicated that most of the observed global temperature rise noticed since the mid-20^{th} century is mainly due to an increase in anthropogenic greenhouse gases (GHGs) concentrations in atmosphere. This has been confirmed through atmosphere-ocean general circulation models (AOGCMs) integrated with the forcing of GHGs, aerosol, volcanic eruptions, solar activity, ozone, etc. Doran and Zimmerman (2009) indicated that among the surveyed 3,184 members of the American Geophysical Union, 97 % of actively publishing climate scientists hold that human activities were accelerating global temperature increases.

More importantly, the spatio-temporal variability of climate (Temp and RF) was proved by various studies (Bewket, 2008; Conway and Schipper, 2011; Seleshi and

Zanke, 2000). ENSO[6] has been among the major driving force for the observed variability of climate across the world (Seleshi and Zanke, 2000). The adverse effect of this hazard has been more prevalent in developing economies like Ethiopia where their livelihood dominantly depends on subsistence agriculture. In 2015/16, Ethiopia was affected by ENSO induced drought and its consequences; i.e., severe food shortage and crisis of livelihood assets (WFP and FAO, 2016). The discussions indicated above prove the prevailing global climate change[7] and variability across the world.

Taking into consideration the findings of IPCC, American Geophysical Union, local climate related studies indicated in the above paragraphs, and a qualitative preliminary assessment on climate variability/change conducted in the Jema watershed, this study has conducted an investigation on the spatio-temporal variation in exposure to climatic stimuli, and examines the vulnerability of livelihood to variability of climate.

2.2 Paradigms in Environment and Development Studies

Taking into account climatic calamities mentioned in the above section, the remaining sections of this chapter deals with paradigms related to environment and development, and the evolution of various development-research approaches.

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[6] An El Ni˜no-Southern Oscillation (ENSO) event is defined by a high Oceanic Niño Index (ONI), which is based on sea surface Temp (SST) departures from the mean in the central equatorial Pacific region. It has severe effect on global weather and climate patterns-leading to reduced rainfall and drought in some regions and heavy rains and flooding in others. This event is a recurrent weather event that takes place approximately every two to seven years and usually lasts between 12 and 18 months.

[7] The climate of a place or region is changed if over an extended period (typically decades or longer) there is a statistically significant change in measurements of either the mean state or variability of the climate for that place or region (UN/ISDR, 2004). In this context variability refers to a statistical difference in weather condition to be observed with in a shorter (eg: inter-annual and inter-seasonal) period of time.

2.2.1 Economic Growth versus Environmental Protection

This topic is dedicated outlining some of the major paradigms that deal specifically with the relationship between economic growth[8] and environmental protection. To date, there have been three perspectives that attempt to explain the integration between economic growth and environmental protection (Todaro and Smith, 2012). The first view states that both economic growth and environmental protection can be exercised in harmony at the same time. According to this view, one complements the other. On the other hand, the second view argues that economic growth and environmental protection are competitive. That is, one is achieved only at the expense of the other. The third view, which is known as the mixed motive model (Environmental Kuznet's Curve) claims that the nature of relationship between economic growth and environmental protection depends on the stage of economic development. Until high stage of economic development is achieved, resource consumption surpasses resource generation. That is, when the economic structure gets improved, there would be a possibility to allocate more funds for environmental protection.

The Ethiopian government with a goal of realizing sustainable development[9] has planned at least on paper or policy level to exercise green economy, and achieve an outcome combining economic growth and environmental protection together

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[8] The concept economic development is broader than economic growth. The former consists of change in both socio-economic and biophysical aspects including gross domestic/national product (GDP/GNP), per capita income (PCI) and their distribution, education, health, natural resources, and environment; whereas the latter one deals with GDP/GNP and PCI.

[9] Development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts: the concept of "needs", in particular the essential needs of the world's poor, to which overriding priority should be given; and the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and the future needs (WCED, 1987).

(MOARD, 2010). As it is a country where most farmers rely on subsistence agriculture, such prioritization of environmental protection is still at its early stage. The validity of this proposition depends on the strength of Kuznet's global observation and interrelation construct.

2.2.2 Watershed and Agroecological Zone Based Research and Development

Ethiopian government anticipating the problem of soil erosion, drought and famine, has, from 1970 to 1990, carried out physical soil and water conservation (SWC) activities together with external donors (WFP) mainly on farmlands of Ethiopian highlands (Admassie, 2000). Moreover, afforestation and reforestation efforts were also made on communal lands. Initially (from 1970 to 1990), the whole process was regarded as part of an aid package and it was termed as food-for-work. In the process of implementing such activities, farmers participated as laborers who were paid in kind (wheat and food oil). It was a national campaign prescribed by the government with the help of external donors (Admassie, 2000; Azene, 2007). Later on, beginning from 1990, the food aid SWC activities were transformed into development programs and included as a package in agricultural extension. Despite these efforts, land degradation (MOARD, 2010; Nyssen, et al., 2000; Selassie et al., 2015, Setegn, 2009) and food insecurity (Admassie, 2000; World Bank, 2010; Amare, 2002; Degefa, 2005) remained prevalent challenges in the country.

In principle, productive and sustainable land use demands both suitable technologies and closely matched approaches that are flexible and responsive to the changing complex biophysical and socio-economic environments (Conway and Schipper 2011; Scoones, 1998). Scholars agree that watershed has to be taken as an ideal geographic home for planning, development, and management of the resources. Depending on the nature and objective of the planning, one may consider undertaking such efforts on larger geographical scale, like river basin or sub-basins. Watershed management is a rather comprehensive and integrated approach to livelihood resources management. It aims at integrating socio-economic and natural resource profiles (Bewket, 2003; FAO, 2007; Gregersen et al., 1996). However, it was only very recently, in 2005, that MOARD has developed a guideline that supports the need for adapting and implementing integrated watershed management at national level (Desta, et al, 2005).

On the other hand, Brouwer and Jansen (1989), Endeshaw (2014) and Simane, et al. (2014) argued that depending on its topographic complexity a watershed needs to be delineated into relatively more homogenous areas, i.e., AEZs. At least theoretically, AEZ has been proposed as a guideline for characterizing patterns of agriculture and its development at national level (MOARD, 2000). Ethiopia is a highland country category wise, and the local agroecological Zones of the country have been delineated employing agroclimatic model, i.e., based on agroclimatic requirement like length of growing period (LGP) that primarily depends on elevation differences (Table 2.1) (Hurni, 1998). It is recognized that variation among agroecological zones reflects the general features of soil, climate, crop type, LGP[10], and farming system (Hurni, 1998; MOARD, 2000). This sounds logical mainly for adjacent AEZs situated in a given watershed or basin, i.e., the same AEZ located in different geographical regions may not experience the same crop pattern, biophysical and farming system. In such

[10] LGP refers to the period of a year when both temperature and moisture conditions are suitable for crop production (FAO, 1996).

instances, adapting agroecosystem Zoning (AES zones) based development approach has been found to be more appropriate (Simane, et al., 2014). While delineating agroecosystem zones, in addition to elevation, attention needs to be paid to characterization of soil, crop type, vegetation, fauna and other indicators. The concept agroecological zone was used in the place of agroecosystem zone in the studies of MOARD (2000) and Hurni (1998).

AEZ	Elevation (m)	ATRF (mm)	Major crops	LGP (day)
Arid lowland (Bereha)	<500	< 900	sorghum, *nug* [11] (Guizotia Abyssinica), Dagusa[12] (Eleusine Coracana), groundnut	<120
Dry to Moist Lowland (Kolla)	500-1500	900-1400	sorghum, *nug*, , groundnut	<120; 120-240
Dry to Wet Cool Highland (Weyna-Dega)	1500-2300	>900; 900-1400	*teff* [13](Eragrostis), maize, sorghum, *nug* , wheat, Dagusa, *inset*[14](*ventricosum),* barley	<120; 120-240
Moist to Wet Cold Highland (Dega)	2300-2700	900-1400; >1400	barley, wheat & pulse	120-240; >240
Moist to Wet Alphine (Low-Wurch)	3200-3700	900-1400; >1400	barley	120-240; >240
High Alphine (High-Wurch)	>3700	>1400	none	>240

Adopted from Hurni (1986). LGP (length of growing period). A place that receives 900mm to 1400mm RF is considered as moist, whereas <900mm is dry, and >1400mm is wet.

Table 2. 1. The local agroecological zones in Ethiopia and their agronomic features, analyzed at the scale of 1:1,000,000

[11] *Nug* is an annual herb grown for edible oil.
[12] *Dagusa* is named as finger millet in India.
[13] *Teff* is a traditional Ethiopian cereal*)*, which is endemic to Ethiopia and Eritrea (although it is also grown in the U.S.A. today), and occupies about 20% of the cultivated land in Ethiopia (Hurni, 1998).
[14] *Inset* or false banana is a further endemic agricultural plant grown in higher-rainfall regions of the country in the Weyna Dega Belt

The number of agroecological zones to be identified depends on the number of variables and spatial scale to be employed in the classification. For example, the 6 AEZs indicated above were identified based on the analysis of LGP that primarily depends on elevation; whereas, taking into account highly aggregated multiple variables i.e. elevation, climate, soil type, vegetation and fauna, the MOARD identified 32 AEZs in the country (MOARD, 2000). In such instance, the term AEZ that was used by the MOARD (2000) and AES that was used by Marten (1988) and Simane et al. (2014) may be used interchangeably. This study adopted the former approach of AEZ classification mainly because the analysis was primarily interested to identify geographical areas that differ in the distribution of crops and livestock, which in Ethiopian case mainly depend on elevation differences. This argument is true especially for the comparative analysis to be made between or among adjacent AEZs.

In 2001, MOARD and WOCAT established the Ethiopian overview of conservation approaches and technologies (EthioOCAT). The document was titled *"sustainable land management technologies and approaches"* (SLM) (MOARD, 2010). Its aim was to realize sustainable soil and water management through scaling up indigenous and introduced practices. SLM focuses on the use of land resources, including soils, water, animals and plants, for the production of goods to meet changing human needs, while simultaneously ensuring the long-term productive potential of these resources and the maintenance of their environmental function. SLM consists of technologies that belong to the following categories: agronomic (intercropping, contour cultivation, mulching); vegetative (tree planting, hedge barriers, grass trips); structural (graded banks or bunds, level bench terrace); and management (land use change, area closure, rotation grazing). In the SLM, watershed and AEZ were recognized as a reasonable spatial framework for the planning and development of livelihood assets.

In SLM (watershed and AEZ based planning and utilization of resources), the argument of Brouwer and Jansen (1989) and Gomez and Jones III (2010) *“nature is systematically arranged”* is implied. And yet, the existence of variation in farming system could result in spatial variation in structure and function of the AEZs. As stated in the work of Matren (1987) and Scoones (1998), the features of these homes are not static; rather it has been in a continuous change observable at a human time scale. There are also features that evolve over a longer period of time. Hence, to observe the impact of agricultural research and development efforts, several years (from 5 to10 years) is required depending on the actual environment.

2.2.3 From ad-hoc response to Disaster Risk Management (DRM)

Economic losses from natural and human induced disasters have topped one trillion US dollars worldwide since 2000 (UN/ISDR, 2011). Yet, about 95% of humanitarian finance is still spent on responding to disasters and their aftermath, with less than 5% spent on prevention and mitigation of disaster risks (Kellett and Sweeney, 2011). This fact was mainly prevalent in sub-Saharan countries where a large proportion of communities are vulnerable to a wide range of disasters (FAO, 2004).

In the history of Ethiopian economy, drought, flood, human and livestock epidemics, crop pests and conflict were recorded as the major striking disasters (MOEF, 2011). It was unfortunate that before 1973, there was no any formal institutional structure that could take strategic measures to avert disaster risks in Ethiopia. Instead, ad-hoc response to crisis was the most familiar way out across the country over decades and centuries. The evolution of disaster risk management formal institution in the country was conceived in 1973/74 with the establishment of the Relief and Rehabilitation Commission (RRC) (Order No. 93 of 1974 cited in Abebe, 2009). Its mandate was providing relief assistance to drought affected people in the northern part of Ethiopia particularly in Wollo and Tigray. In 1979, the relief and rehabilitation commission was reorganized and merged with settlement and Awash Valley Development Authorities (Proclamation No. 173/1979 cited in Abebe, 2009). In 1995, the commission once again reorganized and changed into Disaster Prevention and Preparedness (DPPC) (Proclamation No. 10/1995 cited in Abebe, 2009). At this stage, its mandate was upgraded into relief supplies and disaster prevention through linking relief to development. DPPC was renamed again as the Disaster Prevention and Preparedness Agency (DPPA). But still, the system has limited itself working on saving lives. Therefore, its contribution to reduce vulnerability to disaster risks as well as poverty reduction was minimal.

In principle, it is recognized among the scientific community that without a major increase in investment to prevent and mitigate current and future risks, spending on relief and reconstruction are likely to become unsustainable (MOEF, 2011; Mesfin, 1984, MOFED, 2006, UN/ISDR, 2011). In the mean time, at international level, DRM was definitely addressed on the international policy agenda at the sustainable development and climate change negotiation that was made at the summit of Group of 20 (G20) leaders in Mexico in 2012 (http://www.g20.org/index.aspx). It was also the topic of IPCC's special report on managing the risks of extreme events and disasters to advance climate change adaptation. This document highlighted the links among disaster, climate change, poverty and weak governance (Griggs and Noguer, 2002).

Likewise, in order to shape the orientation of DRM and put into effect in the national economic vision, i.e., *"to be become a middle income country by 2025"*, the government of Ethiopia has showed a vested interest to establish a holistic DRM structure with in the economic development policy documents (SDPRP, 2002 and PASDE, 2006) of the country. As part of accomplishing this vision, following the launching of Business Process Reengineering (BPR) in 2007, Disaster Risk Management and Food Security Sector (DRMFSS) was established under the Ministry of Agriculture and Rural Development (MOARD) in 2008, and replicated to all national regional states of the country (Abebe, 2009). The Government of Ethiopia has ratified a comprehensive DRM policy in 2013. The policy is adopted with a vision of "*to see capacity for withstanding the impact of hazards and related disasters at national, local, community, household, and individual levels; and the damages caused by disasters are significantly reduced by 2023"* (MOEF, 2013). To put this vision into effect, Early Warning and Response Directorate (EWRD) and Food Security Coordination Directorate (FSCD) were instituted and placed under DRMFSS. Early Warning and Response Directorate launched programs useful to reducing disaster risk and impact of disasters through establishment of a comprehensive disaster risk management system, whereas Food Security Coordination Directorate consists of programs that are mandated to run productive safety net program, household asset building and resettlement program to enable chronically food insecure people to attain food security and significantly improve the food security situation of the transitorily food insecure (MOEF, 2011).

In DRM policies and strategies and livelihood vulnerability assessment, there are underpinning concepts (i.e., hazard, disaster, risk, exposure, resilience and vulnerability) in creating a common understanding among scholars and development agents who are working at local, regional and international levels. The definition of these concepts is presented in Box 2.1.

*"**Capacity:** refers to a combination of all the strengths and resources available within a community, society or organization that can reduce the level of risk, or the effects of a disaster. Capacity may include physical, institutional, social or economic means as well as skilled personal or collective attributes such as leadership and management. Capacity may also be described as capability to mitigate, adapt and cope with risks."* *"**Disaster:** is a serious disruption of the functioning of a community or a society causing widespread human, material, economic or environmental losses which exceed the ability of the affected community or society to cope using its own resources. A disaster is a function of the risk process. It results from the combination of hazards, conditions of vulnerability and insufficient capacity or measures to reduce the potential negative consequences of risk."* *"**Disaster Risk Management:** refers the systematic process of using administrative directives, organizations, and operational skills and capacities to implement strategies, policies and improved coping capacities in order to lessen the adverse impacts of hazards and the possibility of disaster."* *"**Exposure:** means people, property, systems, or other elements present in hazard zones that are thereby subject to potential losses."* *"**Hazard:** refers to 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. Natural hazards can be classified according to their geological (earthquake, tsunamis, volcanic activity), hydrometeorological (floods, tropical storms, drought) or biological (epidemic diseases) origin. Hazards can be single, sequential or combined in their origin and effects."* *"**Resilience:** refers to the capacity of a system, community or society potentially exposed to hazards to adapt, by resisting or changing in order to reach and maintain an acceptable level of functioning and structure. This is determined by the degree to which the social system is capable of organizing itself to increase its capacity for learning from past disasters for better future protection and to improve risk reduction measures."* *"**Risk:** means all about the probability of harmful consequences, or expected losses (deaths, injuries, property, livelihoods, economic activity disrupted or environment damaged) resulting from interactions between natural or human-induced hazards and vulnerable conditions."* *"**Vulnerability:** refers to the conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards." Adopted from UN/ISDR (2004).*

Box 2. 1. The definition of underpinning concepts in DRM

These definitions are adopted from UN/ISDR terminology web archive (UN/ISDR, 2007), and are believed to be used synonymously among institutions like Integrated Research on Disaster Reduction, Global Network of Civil Society Organizations for Disaster Reduction, UN/ISDR, Ethiopian National DRM & Food Security that have been working on DRM.

2.2.4 Vulnerability to Climate Variability Analysis

Economic development researches (Brouwer and Jansen, 1989; Marten, 1988; Wezel and Soldat, 2009) have been schematizing the properties of agroecosystem into the topics of productivity, stability, sustainability, equitability and vulnerability. Nevertheless, the boundaries of these features have not been sharp. These properties exist in an interactive manner. Fussel and Klein (2006) stated that vulnerability has become an emerging and fundamental concept for climate science and development policy, mean while scholars' effort that have been made on assessing vulnerability to climate change triggered assessment practices and formulation of analytical frameworks.

With regard to delimiting the scope of factors (components) of vulnerability analysis, studies have identified three different analytical frameworks. These are socio-economic or econometric framework (Blaikie et al., 1994; Forsyth, 2004; Zimmerer and Bassett, 2003); physical framework (De Lange, et al., 2010; Kaly and Pratt, 2000; Setegn et al., 2009; Teferi et al., 2016); and livelihood, integrated or indicator framework (Eakin and Luers, 2006; Hahn et al., 2009; Simane et al., 2014; Sullivan and Meigh, 2005). In the integrated approach, vulnerability analysis is conducted through selecting locally customized essential indicators from the whole set of livelihood assets, and systematically combining the selected indicators. MOEF (2014), IPCC (2004), UN/ISDR (2004), Ethiopian National DRM & Food Security directorate (2013) have started to give emphasis on employing analysis of livelihood vulnerability to climate change for developing more scientific adaptation planning zones.

In examining the concern and nature of previous studies that focus on vulnerability to climate change, four major stages are identified within three generations (Table 2.2) (Fussel and Klein, 2014). The first generation vulnerability analysis to climate change/ variability (the 2nd stage) is an extension of a (climate) impact assessment (the first stage). The step from climate impact assessment to first generation vulnerability assessment is characterized primarily by the evaluation of climate impacts in terms of their relevance for society and for their potential adaptation. In the second generation vulnerability assessment, the focus of studies involves a shift of focus from analysis of potential adaptive capacity to analysis of feasible adaptation responses. Studies categorized in the 4th stage 'adaptation policy assessment' are interested in generating information to be used by adaptation decision-makers. In this stage, the emphasis is to contribute to policy making by providing specific recommendations to planners and to policy makers on the ways of enhancing adaptive and mitigative capacity and implementing adaptation and mitigation policies. In this stage, it is essential to consider the feasibility of implementing adaptation options, and their compatibility with other policy goals such as sustainable development, economic diversification, and biodiversity conservation.

Rothman and Robinson (1997) summarized the evolution of vulnerability assessment in the following conceptual trends:

"*As we move on to the most recent stage, it goes from linear to more complex chains of analysis, from non-adaptive to perfectly adaptive to realistically adaptive agents, from simplistic to sophisticated to pluralistic consideration of alternative developing paths, from strictly quantitative to quantitative and qualitative analyses, from science-driven to policy-driven assessments, and from analyses that dictate users to those that involve those users in the actual assessment process."*

	Impact assessment (1st stage)	Vulnerability assessment		Adaptation policy assessment (4th stage)
		First generation (2nd stage)	Second generation (3rd stage)	
Main policy focus	Mitigation policy	Mitigation policy	Resource allocation	Adaptation policy
Analytical approach	Positive	Mainly positive	Mainly positive	Normative
Main result	Potential impacts	Pre-adaptation	Post-adaptation	Post-adaptation
Illustrative research question	What are potential biophysical impacts of climate change and variability?	Which socioeconomic impacts are likely to result from climate?	What is the vulnerability to climate change, considering feasible adaptation?	Which adaptations are recommended for reducing vulnerability to climate change and variability?
Integration of natural and social sciences	Low	Low to medium	Medium to high	High
Spatial scale	National to global	National to global	Local to global	Local to national
Time horizon	Long-term	Long-term	Mid -to long-term	Short-to long-term

Adopted from Fussel and Klein (2014)

Table 2. 2. Stages of vulnerability assessment and their main features

As stated in the climate resilient green economy policy document of Ethiopia (MOEF, 2011), the country has recognized the need to put more effort in to vulnerability assessment employing the 4th stage. That is, the country has developed a strategical policy document that emphasizes the need to put more effort in to facilitating adaptation and mitigation strategies, enhancing adaptive capacity and implementing more appropriate adaptation strategies and the need to enhance the capacity of farming communities in terms of technology, infrastructure, information, social capital, wealth and institution. As shown in the section of analytical framework

(Figure 2.2), the analysis of this study was managed through customizing the contemporary vulnerability assessment framework.

2.3 Integral Factors in Livelihood Vulnerability to Climate Variability Analysis

This section presents the core concepts essential to understand and manage the overall process of the study. It starts with describing principal rural livelihood assets and moves on to discussing factors for livelihood vulnerability to climate variability (exposure, sensitivity and adaptive capacity to climate variability). The section ends up with showing adaptation strategy and related measures that could be taken to minimize the degree of livelihood vulnerability to climate change.

Livelihood Assets

The economic development of a nation depends on the basic material and social assets that people possess (Füssel, 2007). The assets are termed as 'capitals', since goods and services for livelihood are derived from them. Livelihood assets can be grouped under five categories: natural, physical, human, financial and social (Scoones, 1998).

Under the livelihood asset, natural capital includes land, water and biological resources. Crop production at home depends on access to arable land and its size; and livestock rearing is determined by the availability of pasture and water. Some segments of a population may directly rely on natural vegetation for their livelihood through selling firewood, charcoal and wood for house and furniture construction. Physical capital consists of infrastructures such as transport, shelter and irrigation works, as well as the production equipment which enable people to pursue their livelihoods. It involves community infrastructure and household (HD) level property ownership. Human capital consists of the labor available to a HD and other qualities embedded in it such as education, skills, and health. Financial capital refers to the financial resources available to people (whether savings, supplies of credit, or regular remittances) that provide them with different livelihood options. Social capital includes social networks, social claims, social relations, affiliations, and associations upon which people draw in pursuit of livelihoods. Hence, the sustainable livelihood definition encompasses a range of different criteria, some of which may conflict. 'Sustainable livelihoods' is thus a normative concept made up of multiple and, sometimes, contested elements.

Empirical studies conducted in Ethiopia adopted the same conceptual definition to examine issues of livelihood vulnerability (Simane, et al., 2014; Deressa, et al., 2009) and food security (Degefa, 2005) in the country. In order to structure the analytical framework of livelihood vulnerability to climate, this study relied on the aforementioned descriptions.

Livelihood Vulnerability

Employing livelihood vulnerability as an analytical framework in the risk context parallels the growing interest in understanding and enhancing the positive capacities of people to mitigate, adapt, and cope with the impact of hazards, and develop a resilient economic system against disaster risks (Hahn, 2009; Simane, 2014). The presence or absence of fitting socioeconomic and institutional systems to mitigate, adapt or cope with hazards determines a society's or a community's susceptibility or resilience to the impacts of hazards and disaster risks (UN/ISDR, 2004; IPCC, 2004).

The concept of vulnerability is broadly used across a range of disciplines, including economic development (CRD, 2014; World Bank, 2010), climate change and variability (Solomon, 2007), natural resources (McCall, 2008) and social security (Vincent, 2007). However, the diversity of disciplines where the concept of vulnerability is employed ultimately generated variations in defining and operationalzing the concept.

IPCC assessment report (Houghton et al., 2001; McCarthy et al., 2001) defined vulnerability to climate change/variability as follows:

"Vulnerability refers to the degree to which a system is susceptible to climate change, variability and extremes. It is a function of the character, magnitude and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity"

Similarly, Sullivan and Meigh (2005) developed a climate vulnerability index comprised of six livelihood components: resource, access, capacity, and use, environment, and geospatial dimensions. This study adopted the definition of livelihood given in the work of McCarthy et al., (2001) and Sullivan and Meigh (2005) as it was found most appropriate to analyze livelihood vulnerability to climate change. Similarly, the study of Eakin and Luers (2006), Hahn et al. (2009) and Simane et al. (2014) framed livelihood vulnerably in a similar context. Following this conceptualization of livelihood vulnerability, the core meaning of exposure, sensitivity and adaptive capacity to climate variability are framed in the following sections.

2.3.1 Exposure to Climate Variability

Analyzing the profiles of exposure[15] of different livelihoods to climate stimuli has become an integral component in vulnerability assessment (Solomon, 2007).These stimuli are hazards like RF (rainfall) variability and extreme, Temp (temperature) rises, that are considered as the major concerns in the climate system (UN/ISDR, 2011). Communities or systems have been exposed to hazards through climate change and variability, independent of future changes in the climate system, yet climate change and variability may alter the nature of those hazards, potentially increasing future exposure to disaster risks (Luers et al., 2003). Rural people's livelihood is highly dependent on climate situation due to the fact that they largely deal with plants and animals that require optimum microclimatic situations. And yet, the impact of RF and Temp extremes and variability has been direct and huge (MOEF, 2011). Exposure to climate variability can be measured through considering the variability in onset and end datesof rainy season, the duration of rainy season, the average monthly total rainfall (ATRF), and the mean monthly maximum temperature (MTmax) and the mean monthly minimum temperature (MTmin) (Hahn et al., 2009; MOEF, 2011). The impact of a given climatic stimuli may vary in space and time because of variation in wealth, access to information, technological and institutional factors (McCall, 2008). For example, wherever there is a possibility of using irrigation for crop production, water scarcity brought about by drought may no longer be the cause of crop failure (Degefa, 2005; Hahn et al., 2009; Simane et al., 2014).

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[15] Exposure refers to the presence of people; livelihoods; environmental services and resources; infrastructure; or economic, social, or cultural assets in places that could be adversely affected (IPCC, 2007).

2.3.2 Sensitivity to Climate Variability

As part of vulnerability assessment to climate variability, sensitivity to climate variability is estimated in terms of the responsiveness of an agroecosystem to exposure of climate hazards. This is often represented conceptually as a *“dose-response model”* the more sensitive a system, the larger the rate or magnitude of an adverse response to a given hazard. However, the nature of the response may often be secondary to the mechanisms by which it is realized. Sensitivity to climate variability may vary considerably from one system, sector or population to another (McCarthy et al.,, 2001). LCC, LULC, livestock diversity index; crop diversity index, water harvesting potential, accessibility of water sources and LGP for crops could be regarded as a vital indicators in measuring the degree of sensitivity.

As explained by Fussel and Klein (2006), in the second-generation vulnerability assessment and adaptation policy assessment stages (Table 2.2), non-climatic drivers like demographic, economic, sociopolitical, technological, and biophysical drivers are considered explicitly. These drivers affect non-climatic factors like the degree of economic diversification, the level of education, and the strength of social networks that, in turn, determine the sensitivity of agroecosystem to climatic stimuli.

Land Capability Class (LCC)

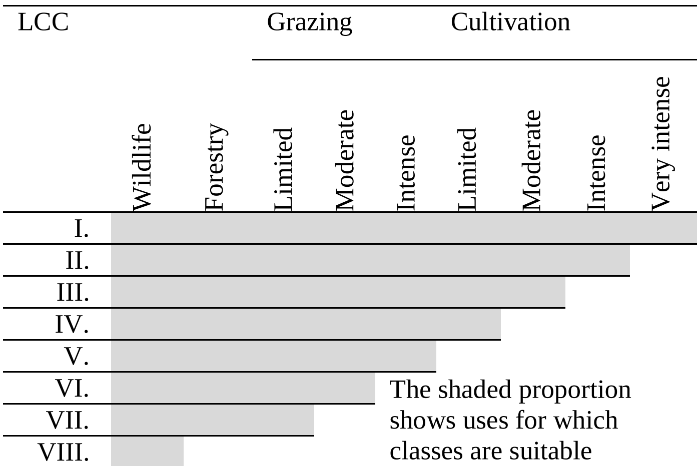
The structure of an agroecosystem is a consequence of environmental setting (i.e., climate, soil, topography, various organisms in the area), agricultural technologies and practices, and farmers’ social setting (e.g., human values, institutions and skills (Brouwer and Jansen, 1989). Likewise, land evaluation framework takes into account biophysical, socio-economic and institutional determinants (Rossiter, 1996). As part of land evaluation, land suitability study is meaningful only in terms of specific kinds of land use, each with their own requirements, e.g. for Temp range, soil nutrient, soil moisture or root depth (Sys and Van Ranst, 1991; and FAO, 2006). On the other hand, land capability classification gives an indication of the general degree of limitation to use. It only considers relatively permanent land characteristics like elevation, slope, soil texture, stoniness, water logging, and soil depth, RF and Temp (Tegene, 2003; Davidson, 1992). LCC guidelines that have been used across the world are imitations of USDA LCC (Klingebiel and Montgomery, 1961; Hockensmith, 1949).

The USDA land capability classification examines a general appraisal of land resources and fails to assess the capability of each kind of agricultural land use separately. In LCC, soil mapping units were classified in to eight classes. The first four classes relate with arable land, in which the limitations on the use and need for conservation measures and careful management increase with class number (Figure 2.1). The intensity of cultivation among arable LCCs varies from very intensive[16] (LCC I) to limited (LCC IV). The remaining four classes are not suitable for cultivation, but can be used for pasture, woodland, wildlife, recreation and other purposes. This LCC information is then translated into land capability sub-classes to identify the nature of the dominant limitation. Next, the sub-classes is classified into land capability units to group together similar types of land requiring the same kind of management, the same kind and intensity of conservation treatments. For instance,

[16] Intensive cultivation or farming is characterized by a low fallow ratio, a higher use of labor and capital (chemical fertilizer, improved seeds and pesticides) per unit of land area. This is in contrast to traditional agriculture in which the inputs per unit land are lower.

land with similar fertility of soil that can be used to cultivate the same kinds of crops with comparable potential yields may be categorized into the same capability unit.

This study examined LCC using limited indicators such as soil texture class (% of particles), range of slope (%), and range of elevation (m), range of ATRF (mm). It was assumed that Temp and LGP are direct reflections of elevation (Hurni, 1998). This assumption is true especially in countries like Ethiopia where relief type of rain is experienced (MOARD, 2000). Thus, to avoid an error that may be created due to double counting, LGP and Temp were not considered in the analysis of LCC. Slope is believed to have a major role in determining the type of land use mainly associated with its effect in runoff. The Ethiopian land use policy discourages using land with 30% slope to cultivate annual crops (MOEF, 2005).



Adopted from Davidson (1992)

Figure 2. 1. Land capability classes and their intensity of land use as prepared by USDA.

Based on the field observation, it was possible to observe the intensity of average daily Temp in the AEZs of Jema watershed, the average ATRF (1228 mm to 1640 mm) received in all the AEZs was perceived to be enough for cultivating any local crop. But still, differences in the average ATRF may create variation in terms of water harvesting potential. Stoniness, water logging and soil depth are not evaluated in this study. Consequently, the LCC analysis may not be regarded as fully comprehensive. As stated in the work of USDA system suggested by Young (1976), in LCC analysis, the critical point is the degree of limitation, not the number of limitations.

Land use-land cover (LULC)

Although land use is generally inferred based on the cover, and though the concepts land use and land cover are overlapping, they are not the same. As stated by FAO (2007), land use refers to the way in which land has been used by humans (such as agriculture, settlements, industry etc.), while land cover infers simply a cover type to a give piece of land either used by humans or not. Over all, in empirical studies (Amare and Kameswara, 2012; Amsalu, 2006; Bewket, 3003; Fisseha, 2011; Teferi, et al, 2013) conducted in the Blue Nile River Basin where the study site is situated, seven major LULC types. These are: Bare land: includes rock outcrops, denuded land and badlands; Bush land: Scrub land; Crop land: includes cultivated and fallow land; Forested land: includes natural forests; woodland; riparian vegetation, vegetation growing along streams; plantation, planted trees either individually or collectively; Grazing land; land under permanent pasture; Settlement land: includes both scattered and nucleated rural settlements; and Water body which includes mainly stream water.

Spatial and temporal differences in LULC have been associated with soil and hydrological processes (Conway, 2000; Meyer and Turner II, 1994). Human alterations of LULC have caused erosion rates to increase in many areas of the world, resulting in land and environmental degradation (McCauley and Jones, 2005). The severity of erosion depends upon the quantity of soil detached and the capacity of the wind and water force to transport it (Morgan, 1995). As both detachment and transport require energy, the characteristics of soils that erode depends on 'erosivity', the energy of the eroding agent (i.e., wind or water), and 'erodeability,' the soil's susceptibility to erosion. Land Cover change influences both the erosive power of the eroding agents and the erodeability of soil (Morgan, 1995).

The immediate driving forces for the temporal change in LULC have been correlated with population size (Amsalu, 2006; Bewket, 2003; Sonneveld and Keyzer, 2003) and poverty (Endeshaw, 2014; Holden et al., 2005) in different directions and magnitudes. Moreover, climate change and variability have also been identified as long term causes (Meyer and Turner II, 1994). For example, based on the study of Kebede et al. (2005), during the last century, variation in climate played a far greater role in the Lake Tana Sub-Basin hydrology more than human factors or other local forces such as deforestation and accompanied changes in runoff, and diversion for irrigation. However, the controversy over the issue remains unresolved.

2.3.3 Adaptive Capacity to Climate Variability and Adaptation Strategy

Adaptive capacity to climate variability

The term adaptive capacity refers to a procedural response to a real or perceived potential harm. That potential may arise from a range of drivers. Some drivers could be biophysical in nature (e.g. climate hazards and extremes) while others could be socially constructed (e.g. demographics, environmental imbalances, or consequences of decision making) (Ebi et al., 2006). Similarly, according to Nelson et al. (2007), adaptive capacity refers to preconditions that enable actions and adjustments in response to current and future external changes dependent both on social and biophysical elements.

In previous studies, adaptive capacity has been measured in terms of resource availability (e.g. social, technological, infrastructural and wealth) (Hahn et al., 2009; Simane,, et al., 2014). Moreover, the institutional and governance networks that exist to deploy those resources have been also essential components in determining successful adaptation (Scoones, 1998). In this study, adaptive capacity was organized under the first four livelihood resources mentioned above.

In countries like Ethiopia where the topography is complex (Conway and Schipper 2011; Selassie et al., 2015; Setegn, et al., 2009; Simane, et al., 2014; Zaitchik et al., 2012), various studies showed that the nature of agroecosystem varies in a relative ly short distance. Whereby, as explained by Eriksen et al. (2007) and Fussel (2007), in the process of measuring livelihood vulnerability in different communities, the integral dynamic concepts (exposure, sensitivity and adaptive capacity to climate variability) need to be tailored to its socio-economic, biophysical and technological contexts.

Adaptation Strategy

Studies by Kelly and Adger (2000) and Thomas et al. (2005) indicated that diverse communities respond to climatic calamities differently. The observed responses, for both short term and long term were technically termed as coping mechanisms and adaptation strategies respectively. Coping mechanism refers to the use of existing resources to achieve short term objectives during and immediately after unusual, abnormal, and adverse conditions of a hazardous event or process. On the other hand, adaptation strategy refers to actions and adjustments undertaken to maintain the capacity to deal with stresses induced as a result of current and future external changes including climatic events (Alland, 1975). Similarly, Maxwell (1996) defined the concepts:

"Coping strategies are the bundle of producer responses to declining food availability and entitlements in abnormal seasons or years, while adapting strategies involve a permanent change in the mix of ways in which food is acquired, irrespective of the year in question."

Mitigation has been also an important long term and preventive strategy predominantly in developing economies so as to reduce climatic stresses caused by exposure to climatic stimuli. The strengthening of coping and mitigative (preventive) capacities is an important aspect of adaptation that builds resilience to withstand the effects of natural and human induced hazards. It indicates that the ability to pursue different livelihood strategies depends on the socio-economic and biophysical assets people possess (Degefa, 2005; Scoones, 1998). Hence, developing appropriate adaptation strategies to the dynamic environment demands establishing data base of vulnerability profiles in terms of a spatio-temporal context.

Previous studies conducted in Ethiopia (Assefa and Bork, 2014; MOEF, 2011; Deressa, et al., 2009; Simane, et al., 2016) showed the presence of local knowledge and experience among farmers. Application of more chemical fertilizer, construction of physical soil and conservation structures like terracing and soil/stone bund, changing land use from cropland to plantation land-eucalyptus tree were identified as the major adaptation strategies. Off-farm (seasonal migration to work as a daily laborer) and non-farm (handicrafts) livelihood strategies, crop rotation and switching crop diversity were also the most common adaptation strategies in rural areas where mixed "crop-livestock" farming was cultured. This was proved by the local studies indicated above. MOARD has also identified similar mechanisms that could be applicable to moist highland adaptation planning zone where the study watershed is located. Moist highland is one of the 14 adaptation planning zones identified in the country (Annex 2.1). This zoning was analyzed depending on the 32 AEZs of the country (MOEF, 2011). However, the level of relative priority would vary, and individual sub-options would differ depending on the nature of existing risks and major source of livelihoods to be observed in a given locality.

Exploring appropriate ways to facilitate[17] and implement[18] adaptation strategies for strengthening communities' adaptive capacity has become an essential element in the contemporary development researches (Fussel and Klein, 2006) (Figure 2.2). Previous studies (Assefa and Bork, 2014; Conway and Schipper, 2011; Kelly and Adger, 2000) explained the need to identify and recognize farmers' adaptation strategies to better manage the degree of disaster risk. These adaptation strategies might have been delivered both with the help of GOs/NGOs and with farmers' own responses, also called 'autonomous adaptation'. Yet, mal-adaptation practice (hazards) like encroaching into steep slopes in search of new farmlands was also observed in Ethiopian highlands (Amsalu et al., 2007; Teferi, et al., 2016; Simane, et al., 2013; Zeleke, 2000).

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[17] Facilitation refers to activities that enhance adaptive capacity, such as scientific research, data collection, awareness raising, capacity building, and the establishment of institutions, information networks, and legal frameworks including bylaws for action.

[18] Implementation refers to activities that actually avoid adverse climate impacts on a system by reducing its exposure or sensitivity to climatic hazards, or by moderating relevant non-climatic factors.

As part of facilitating viable adaptation and mitigation strategies that may enhance the adaptive and mitigative capacity of rural communities, carbon payments is strongly recommended combined with sustainable utilization of wood and non-wood products to create sufficient economic incentive for forest plantation development (WBISPP, 2004). Considering payments made for other environmental services, such as reduced soil erosion and nutrient cycling, the benefits could even be higher (MOEF, 2014).

In order to enhance the adaptive and mitigative capacity of rural communities, the Ethiopian government (MOEF, 2011) has identified the following facilitation themes: (1) Construction of roads and other infrastructure; (2) Rolling-out enhanced extension services; (3) Incentives for livelihood diversification; (4) Asset creation and protection schemes; and (5) Payments for ecosystem services including carbon trading. As noted by the Ministry of Environment and Forest (MOEF, 2014), the prospect for Ethiopia to access to carbon finances was high given the large area potentially eligible for clean development mechanism (CDM[19]) and reducing emissions from deforestation and forest degradation (REDD[20]) and (REDD+[21]) international carbon projects. Similar to CDM, REDD+ pilots are in preparatory stages in Ethiopia by various nongovernmental organizations, such as FARM Africa/SOS Sahel in the Bale eco-region (500,000 ha). Taking into account the nature of a development sector, there need to be prioritizing the

[19] The Kyoto Protocol that was first agreed in 1997 introduced three market-based mechanisms: the International Emissions Trading (IET), The Joint Implementation (JI) and the Clean Development Mechanism (CDM).

[20] At the 13th Conference of Parties in Bali in 2007 a “Bali Road Map’ was agreed upon which includes efforts to include a new mechanism for reducing emissions from deforestation and (forest) degradation (REDD).

[21] REDD+ is an extension of REDD, and refers to reducing emissions from deforestation + reducing emissions from forest degradation + conservation of forests + sustainable forest management + enhancing forest carbon stocks.

level of government intervention. Yohannes (2016) stated that water related adaptation and mitigation practices can be put into place with a strong support of GO and NGO.

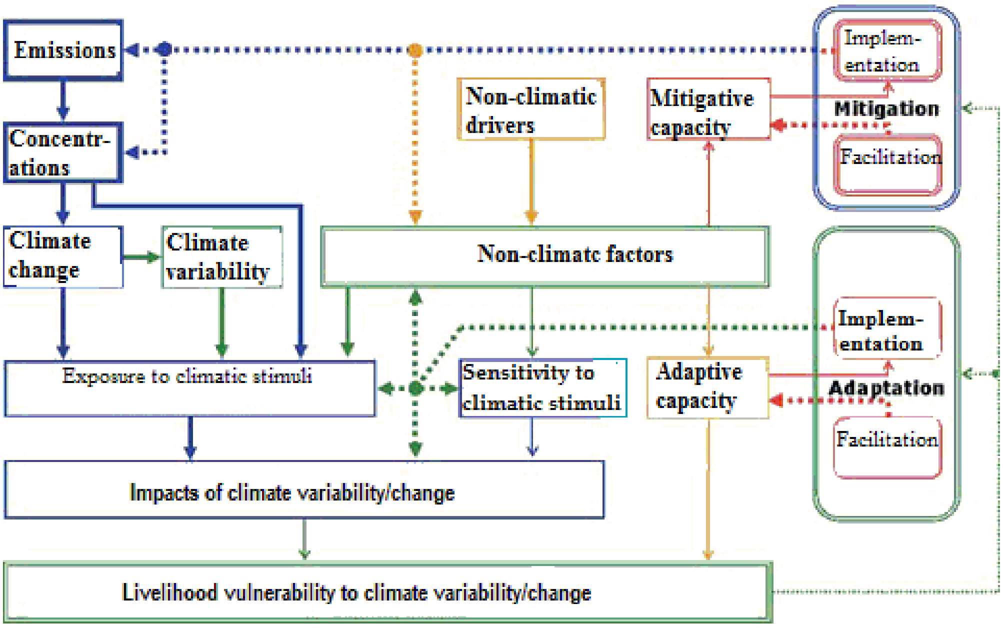
The Ministry of Forest (2014) concluded that Participation of Ethiopia in REDD+ will generate huge environmental, social and economic benefits. However, constraints related to weak institutional capacity, policy gaps, competing interests and weak implementation of polices, and absence of defined benefit sharing mechanisms could hinder the implementation of carbon projects and other payments of ecosystem services.

2.4. Analytical Framework of the Study

As constituent elements that form the basis of the analytical framework of the study, factors, profiles and indicators of livelihood vulnerability and the direction of relationship are illustrated in this section.

An agroecosystem ties people, crops, weeds, animals, micro-organisms, soil, and water together into a functioning, on-going ecosystem. Hence, it is intricate and can never be fully described, nor can it be fully comprehended. But still, simplification is a practical necessity of livelihood vulnerability analysis and a prerequisite to effectively communicate the results of analysis to agricultural practitioners. And yet, it is important to note that simplifying agroecosystems without losing the essence of key relationships in a system has as a whole been challenging.

This study attempted to analyze vulnerability by adapting an integrated (livelihood) approach through the use of vulnerability index. That is, the latest stage of vulnerability analysis to climate change/variability was adopted. Accordingly, the major factors (exposure to climate variability, agroecosystem sensitivity to climate variability and adaptive capacity) of livelihood vulnerability to climate variability and their synergy are illustrated as presented in Figure 2.2. The profiles and specific indicators under each factor of livelihood vulnerability are presented in Table 2.3. The proposed inter-linkage among the factors (and their profiles) of the livelihood vulnerability to climate variability is illustrated in Figure 2.3.



Adopted from Fussel and Klein (2006)
Figure 2. 2. Analytical framework for livelihood vulnerability to climate change/variability analysis

Physical cause effect relationship (A causes B)

Effects of human action

Functional relationships (A partly causes B)

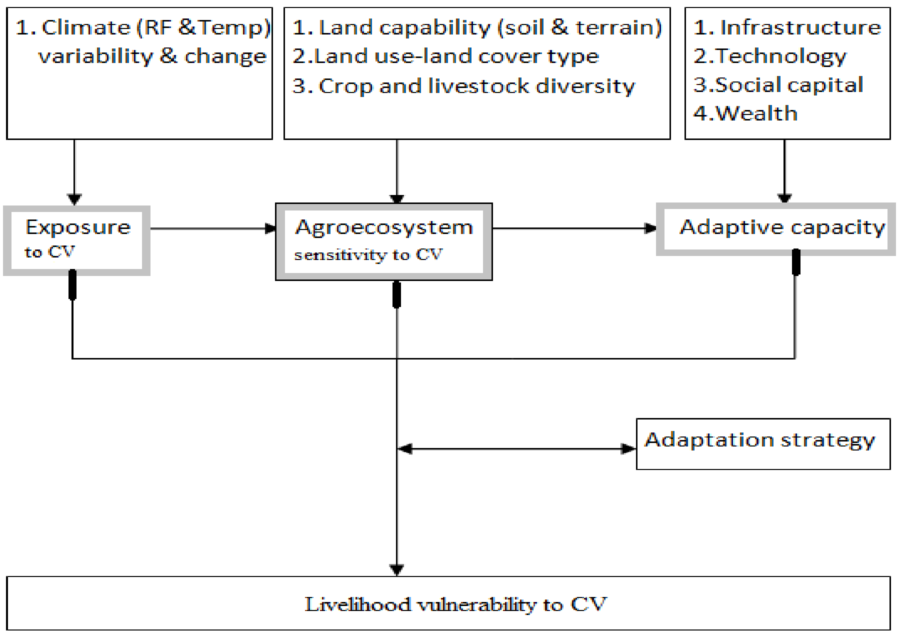
Perception and interpretation of information

- Blue boxes belong to impact assessment (the 1st stage of vulnerability assessment);
- Blue and green boxes belong to the 2nd stage of vulnerability assessment;
- Blue, green and orange boxes belong to the 3rd stage of vulnerability assessment; and
- All boxes belong to the 4th stage of vulnerability assessment.

Box 2. 2. Key to the illustration presented in Figure 2.2

The procedure of assigning the direction of relationship between vulnerability and the three major factors affecting it was adopted from the vulnerability study (Hahn et al., 2009). A negative sign was assigned to profiles of exposure and sensitivity to climate variability, while a positive sign was attached to adaptive capacity to climate variability. Unlike exposure and sensitivity, adaptive capacity was assumed to have inverse correlation with vulnerability. The main reason behind this is that areas exposed to climate variability were more sensitive to damages, assuming constant adaptive capacity.

The diversity and quantity of indicators to be considered for characterizing each livelihood vulnerability profile/factors depends on the complexity of the actual livelihood system to be studied; availability of finance, time and skill. Hence, the choice of indicators under each profile (Table 2. 3 and Figure 2.3) is customized in accordance with the context of the nature of north-western highlands of Ethiopia, i.e., the broader region where the study site is situated. Overall, a total of 57 indicators were considered in the LVI.



Modified from Fussel and Klein (2006), Hahn et al. (2009), Simane et al. (2014)

Figure 2. 3. Factors and profiles of livelihood vulnerability to climate variability (CV) and their inter-linkages specific to this study

The outputs of the 1st objective (climate analysis) and 2nd objective (soil texture analysis) are used for the 3rd objective, i.e., the analysis of LCC. Moreover, the output of the 2nd (soil texture analysis), 3rd (LCC analysis) and 4th (LULC type analysis) objective are ultimately used for the analysis of agroecosystem sensitivity to climate variability, and its result is placed within the 4th section, i.e., analysis and discussion of LULC type.

Profiles/factors	Indicators
Exposure to climate variability	Variability in onset time (being late) of rainy season in the last 15 or 20 years (in month), Variability in end date(earlier) of rainy season in the last 15 or 20 years (in month), Variability in duration of rainy season (in month), Standard deviation of the average ATRF (in mm), Standard deviation of the average daily max temp by month (in ^{0}C), and Standard deviation of the average daily min temp by month (in ^{0}C).
Agroecosystem sensitivity	Area coverage (proportion) of arable land-LCC II (in km^2), Area coverage (proportion) of arable land-LCC III (in km^2), Area coverage (proportion) of arable land-LCC IV (in km^2), Area coverage (proportion) of arable land-LCC V (in km^2), Area coverage (proportion) of bush land (in km^2), Area coverage (proportion) of forest land (in km^2), Area coverage (proportion) of water body, stream water (in km^2), Accessibility (in minutes) of spring/stream water, Average ATRF (in terms of rain water harvesting potential) (in mm), Livestock diversity index, Crop diversity index, Area coverage (proportion) of bare land (in km^2), Gully as a major environmental problem (in qualitative scale), and LGP for major growing crops (in week). *Runoff and flooding
Infrastructure	HDs (%) having access to road (weather or gravel) to go to their regular market, HDs (%) having access to electricity (power), Distance to access regular market (in minute), Distance to access health center (in minute), Distance to access schools (grade 1-4, 5-8, and 9-10) (in minute), and Distance to access telephone service (tele-network) (in minute).
Wealth	Total agricultural land size *(in Kada*)*, Irrigable land size (in *kada),* Size of ox per HD (count), Size of caw (count), Size of heifer (count), Size of bull (count), Size of sheep and/or goat (count), Size of mule (count), Size of horse (count), Size of asses (donkey) (count), Size of hen (count), Income from market price of barley (in **birr*), Income from potato (in birr), Income from maize (in birr), Income from *teff* (Eragrostis) (in birr), Income from pea (in birr), Income from *nug* (Guizotia Abyssinica) (in birr), Income from red onion (in birr), Income from non-farm (handicrafts) practices (in birr), Income from off-farm (seasonal migration-daily labor) (in birr).

Technology	Proportion of HDs who were using chemical fertilizer (*DAP& urea), Proportion of HDs who were using improved seed, Proportion of HDs who domesticated improved livestock hybrid, Proportion of HDs who were using biogas as a source of energy, and Proportion of HDs who were using mirt-stove (energy/firewood efficient stove) as a source of energy.
Social[22] capital	Proportion of literate HDs, Proportion of family members who were attending school, Proportion of family members at working age (15-65), HDs (%) experienced in taking credit from local financial institution, HDs (%) experienced in social gathering for natural resource conservation, and Regular number of working days in a month.

*Runoff and flooding were among the major agroecosystem sensitivity indicators in the study site, and yet these were not included directly in the analysis assuming that their pattern would be implicated in LULC & LCC; **kada:* one fourth of a hectare; *1birr= ~$0.048USD during the time of survey; *DAP: diammonium phosphate.

Table 2. 3. Indicators considered for measuring profiles/factors of livelihood vulnerability to climate variability.

The indicator (integrated approach) approach, apart from its merit in monitoring trends and exploring conceptual frameworks, has a limitation in that the indices are limited in their application by considerable subjectivity in the selection of variables and their relative weights, and by the availability of data at various scales (Luers et al., 2003). It is also important to realize that all indicators of livelihood vulnerability might not be exhaustively included as part of livelihood vulnerability analysis of this study (Table 2.3). In addition, even if feasibility analysis is one component of adaptation policy assessment framework, the feasibility of implementing the observed adaptation options was not part of the investigation in this study. And yet, in addition to the preliminary FGD that was made in the Jema watershed, previous studies (MOEF, 2011; Hahn et al., 2009; McCarthy et al., 2001; Scoones, 1998; Simane, et al ., 2014) were consulted to better inform the identification and organization of indicato rs under each livelihood vulnerability profile.

[22] In this study human capital (like literacy and labor) is included under social capital.

Chapter Three

3. Research Methodology

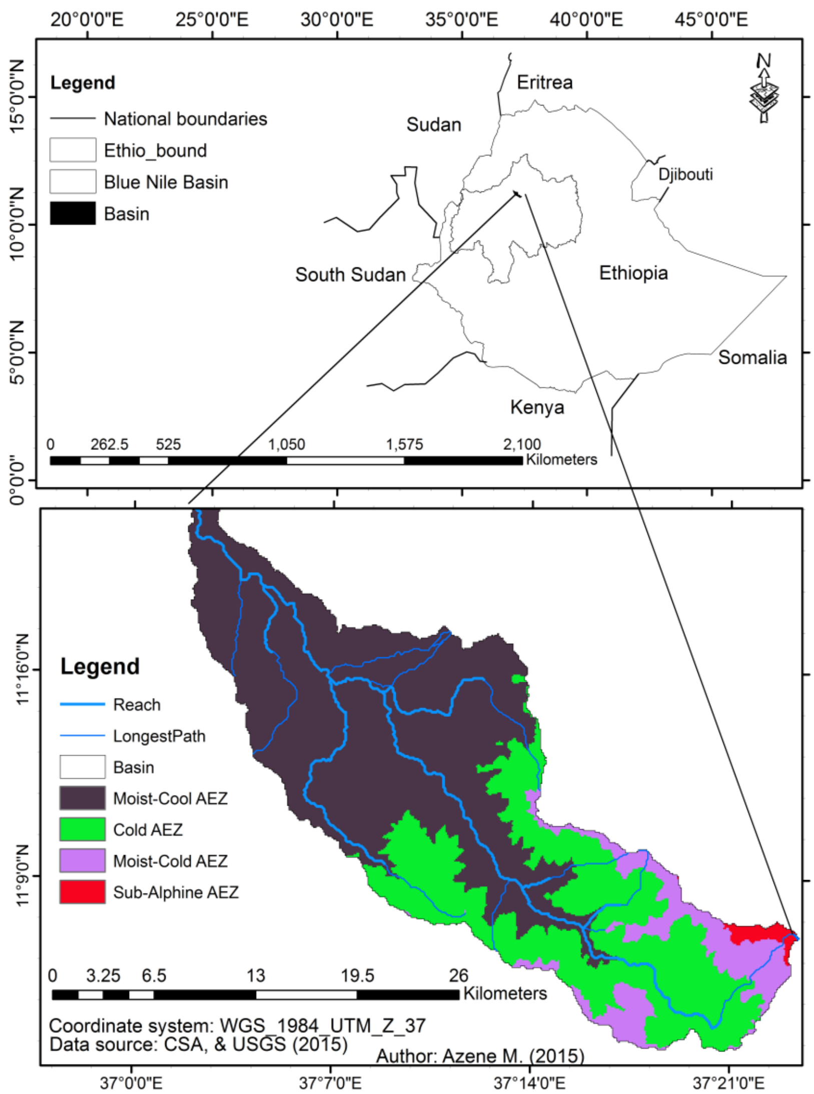
In this chapter, the description of the study site, the research methods and materials, and the methodological approaches and theoretical assumptions (paradigms) are discussed. It begins with description of the Jema watershed, the justification for selecting the site, and the explanation of theoretical assumptions and approaches for using the selected research methods and materials. The chapter ends with a detailed description of the specific research materials and methods employed for the investigation.

3.1 Description of the Study Site

The Jema watershed is situated within $11^0$22’0’’N to $11^0$3'30"N and $37^0$2'0"E to $37^0$23'30"E (DEM 30m r). It is part of north-western highlands of Ethiopia in the Lake Tana Sub-Basin[23], the Upper Blue Nile River Basin (Figure 3.1). Its geographical area covers ~483 km^2 and has an elongated physical setting. Administratively, the study site is situated in *Mecha, Sekela, Quarit, and Yilmana Densa* districts (*Woredas*), found in West (*Mirab*) *Gojjam* Administrative Zone of the Amhara National Regional State. About 80% of the study area falls in *Mecha* district. The Jema River stretches from Adama Mountain (at *Fengeta-Chegode* sub-

[23] The area of Lake Tana Sub-Basin at its outlet is 15,321 km^2 (SMEC, 2008). It has a dendrite type of drainage network. The main tributaries (permanent rivers) to the lake are Gilgel Abbay (Little Nile River), and the Megech, Gumara and Rib rivers contribute 93% of the inflow (SMEC, 2008). The Jema watershed covers ~10 % of the geographical area of Gilgel Abbay watershed (5004 km^2) which contributes the largest water inflow to the lake (Dile, et al., 2013). The sub-basin is identified as a region for irrigation and hydropower development, which is vital for food security and economic growth in Ethiopia (McCartney et al., 2010).

district/*kebele*) in *Quarit* district to *Gora-Got* Sub-district in *Mecha* district where it joins Little (*Gilgel*) Abay river, the largest tributary (in terms of water volume) of Lake Tana Sub-Basin. The road line distance that takes to the watershed is estimated to be 80 km South of Bahir Dar, the capital of the regional state, and 500 km north of Addis Ababa, the country's capital.



NB: The scale[24] of the maps may be distorted while zoming (for enhnacing map) them in the microsoft word program

Figure 3. 1.Location map of the Agroecological zones (AEZs) of Jema watershed

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[24] Based on its real map scale, the area of the watershed is 483km^2 .

Literature indicated that volcanic rocks of Late-Tertiary to Quaternary age dominated the geology of the watershed. (MoWER, 2012; Poppe, et al., 2013). The site is characterized by complex terrain with gentle slope, hilly landscape, and steep slope. The data generated from SRTM 30m r DEM indicated that elevation of the site ranges from 1895 to 3518 m.a.s.l (Table 3.1). The value of elevation declines as we go from south-east to north-west. The site is generally characterized by moist highland (MOARD, 2000; Hurni, 1998). Based on the local AEZ classification system (Hurni ,1998), the site consists of Moist-Cool highland (Weyina-Dega), Cold Highland (Low-Dega), Moist-Cold Highland (High-Dega) and Sub-Alpine (Low-Wurch) AEZs. The AEZs are categorized under Moist taking into account the average mean annual rainfall (~1400mm) of the Jema watershed. Similarly, based on the AEZ classification made by MOARD (2000), the Jema watershed covers Tepid Moist Mid Highlands, Cool-Moist Mid-Highlands, Cold Moist Sub-Afro-Alphine to Afro-Alphine, and Very Cold Moist Sub-Afro-Alphine to Afro-Alphine AEZs. The former AEZ classification was analyzed based on elevation difference, whereas the latter one was analyzed combining elevation class, highly aggregated soil, crop, and vegetation types.

	AEZs				
	Moist-Cool	Cold	Moist-Cold	Sub-Alphine	Total
Elevation (m. asl)	1895-2300	2301-2700	2701-3200	3201-3518	1895-3518
Area (ha)	28690.53	14863.51	4253.62	436.46	48244.12
%	59	31	9	1	100

Table 3.1. Area coverage of the AEZs of Jema watershed as computed from DEM 30m r

On average, its ATRF is ~1400 mm. About 80% of the total precipitation occurs during summer (*Kiremt*[25]) season. On average, the MTmax and MTmin are ~25^0C and ~7^0C respectively. The National Meteorological Agency of Ethiopia showed that the maximum Temp has been recorded in March, during spring (*Belg*[26]) season (NMA, 2014). The main soil orders have been Alisols, Nitisols and Vertisols (FAO, 1998). In terms of soil color, red, brown and black soils dominate the site (WGAZ, 2013).

The total average population growth rate of West Gojam Administrative Zone, where the study watershed is situated,was estimated to be ~3 % person/year (CSA, 2008). At the regional level (the Amhara Regional State), the average family size was estimated to be 4.6 persons (CSA and World Bank, 2013); meanwhile the population density was ~189.4 persons/ km^2 (BOFED, 2012).

Cropland, grazing land, settlement land, bare land, bush land, wood land, riverine trees, water body, and forest land were LULC types in the site (Minale and Rao , 2012). The livelihood of people has been dependent on subsistence scale mixed farming, i.e., food crop production and livestock rearing. The farming heavly depends on rainfed system with scanty small holding irrigation. According to BOFED (2012), the main crops grown include barley (*Hordeum vulgare*), wheat (*Triticum aestivum*), maize (Zea Mays); potato (*solanum tubero sum*), *teff* (*Eragrostis*), horse bean (*Vicia faba*), pea, and onion (*Allium cepa*). The main livestock types include cattle, sheep, goat, horse, donkey, mule and poultry. A very small proportion of households have

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[25] *Kiremt* season is a local name synonymous with summer season. It stays from June-September.
[26] Belg season is a local name synonymous with spring season. It stays from March-May.

been engaged in off-farm activities like petty trading, weaving, daily labor, smithing and pottery for generating additional income.

3.2 Theoretical Assumptions Underpinning the Research Methods

As an initial step to a research understanding, one has to start by trying to answer the question *"how do I view the world?"* How this question is answered will explicitly or implicitly reveal a world view (Dawson, 2009). At this step, it is also essential to think about fundamental theoretical considerations and philosophical questions that concern the nature of reality (ontology) and how we go about understanding it (epistemology). As pointed out by scholars (Gomez and Jones, 2010), for example, such philosophical concerns need to also include sorting out *"paradigms"*-bodies of theory the researcher follows to guide scientific practice. The researcher is expected to make a number of *"middle level"* decisions concerning methodology and approach: the selection of research objects, the questions directed towards them, the design of the study, and the implications that the objectives set have for the research to be under taken. Finally, at the most concrete and practical level, we find research methods, the ways of collecting and analyzing data, and ways of drawing conclusions from the processes. As Peet (1998) notes, a theory needs to be responsive, steadily updated and reshaped in light of the odds and contradictions that unfold in actual research findings.

To date, in spatial science, critical realism, humanism and post–structuralism are the major theoretical assumptions researchers identify (Del Casino, 2000). Taking an eclectic stand, this study synthesized the views of both spatial science and critical realism. In terms of theoretical assumption and approach of data analysis, unlike humanism and post–structuralism, spatial science theory assumes the following: space is viewed as a two - dimensional container within which places exist as discrete phenomena with distinct attributes; variations across and interactions between places are measurable, usually quantifiable; each object of analysis has a series of distinct characteristics, including its location within this two – dimensional container; and a descriptive mapping of the spatial locations and characterizing the objects is a first step in assessing causal relations. With regard to researcher–object relations, subjectivity is controlled in favor of objective forms of research analysis and presentation (Gomez and Jones, 2010).

Similarly, unlike humanism and post –structuralism, critical realism assumes the following: events in the world are embedded within wider structures (e.g., capitalism and patriarchy) and their casual mechanisms (e.g., worker exploitation, gender division of labor). For many physical processes, explanation is of a *"necessary"* type: the causal powers operate in the same way from one place to another (Peet, 1998). For social relations, the mechanisms causing change are usually contingent or context specific. Paying attention to contingent contexts including the different spaces in which things happen requires in–depth case study. Social structures and mechanisms are differentiated across local and global contexts (Kothari, 2004).

With respect to analytical approach, in the physical sciences, the researcher remains open to the possibility that causal mechanisms are complexly, contingently, and non-linearly related (Peet, 1998). With respect to researcher-object relations, the theory argues that in social context analysis, researchers assume that individuals have a situated capacity to reflect upon structures and mechanisms, even though they might not have a well-developed theoretical language for articulating them. Though the world exists objectively, our capacity for knowing it in an objective way is limited by our own contingently situated knowledge (Gomez and Jones, 2010).

3.3 Methodological Approaches of the Study

This study is a type of empirical research and relies on experience or observation, without due regard for developing new concepts/theories and/or reinterpreting the existing ones. It is a data-based case study conducted to reach at conclusions capable of being verified by observation and survey methods. As stated in the work of Kothari (2004), this kind of research is appropriate when proof is sought for the existence of interrelationship between/among variables. The research type adopted in study is a mixed one involving integration of qualitative and quantitative approaches of investigation.

During the 1980s, in livelihood studies, there was a move away from extensive questionnaire surveys, regarded by some as time-consuming, costly and ineffective to participatory, more efficient and economical methods (Chambers, 1983). As Homewood (2005) argues, although FGD and participatory mapping methods are used successfully as part of pilot studies, they are no substitute for more in-depth research. In this regard, Ellis (2000) argues that a combination of survey and participatory method (like FGD) help achieve a more complete understanding of livelihood strategies.

In this study, therefore, FGD and SQ data collection tools were employed adapting appropriate techniques and procedures. This was done to generate data from the farmers' point of view, and to assess the observable components of the livelihood and environment. The data collected by using FGD was analyzed in a descriptive manner, whereas the data collected by employing SQ was subjected to inferential statistical analysis. As stated in the work of (Kothari, 2004), unlike experimental and simulation statistics, the purpose of inferential analysis is to form a data base from which to infer characteristics or relationships of population. This requires a survey research where a sample of population was studied (questioned or observed) to determine its characteristics. On the other hand, an experimental approach is characterized by greater control over the research environment, where in this case some variables are manipulated to observe their effect on other variables. Simulation approach on the other hand, involves the construction of an artificial environment within which relevant information and data can be generated.

3.4 Methods and Materials

In this section, essential components of the research materials and methods (sources of data, sampling techniques and procedures, materials, methods, tools, and analysis models) are presented under each of the six sub-topics (objectives) of the investigation. To avoid repetition, the same research materials and methods intended to be used in multiple sub-sections are stated only once under the sub-section that appeared first.

3.4.1 Farmers' Adaptive Capacity and Perception to their Local Environment

As part of investigating the spatial variability in adaptive capacity, in this sub-section, the topic "how to generate and analyze socio-economic data" was discussed. In order to synchronize the analysis of vulnerability with socio-economic status (adaptive capacity) of the local people, focused group discussion (FGD) and structured questionnaire (SQ) were tools employed to generate data. The contents of the FGD and the SQ are appended in Annex 3.1 and Annex 3.2 respectively. The same tools were also used to collect data on households' perception to their local environment, climate variability and change. According to (FAO, 2007), double-track approach is an integrated evaluation system that could help compare findings as perceived by farmers and through scientific judgment. Assefa and Bork (2014) explained that farmers are believed to have real exposure to their locality, and are resourceful to cope with the problems associated with environmental problems. Accordingly, employing farmer-led assessment is considered to be appropriate.

Focus Group Discussion

FGDs were employed to generate qualitative historical data on variability in onset and end datesof rainy season, anomalies in duration of rainy season, and differences in LGP. The same tool was used to generate data on Local Crop Unit (LCU[27]). One focus group discussion (FGD) was made in each of the AEZ. Each FGD consists of 6 to 8 participants. The selection of participants was made purposely taking into account their AEZ and age. For collecting information about climate change, elders were included deliberately in the selection process. Each FGD lasted two hours, and was conducted with the support of a trained moderator. Like the case of structured questionnaire survey, a pilot FGD was made in each of the AEZ for customizing the contents and structure of FGDs. As Ghosh (1985) and Kothari (2004) noted, pilot

[27] LCU (Local Crop Unit) is generated by this study considering the mean value of the most recent 3 years (2014, 2013 and 2012) local market price of local crops. It is believe to be a convenient method for quantifying a wide range of different crop types in a standardized manner to a given locality.

study helps improve skills of addressing questions properly, having effective eye contact, minimize/avoid domination, take down effective notes, understand body language, prob participants for further discussion and control the direction of the discussion. All the procedure implemented to conduct FGDs was exercised as recommended by Kothari (2004) and Taylor and Bogdan (1998).

Questionnaire (Face to Face Structured Interview)

The estimate of a parameter (the study population) from a statistics (selected participants) constitutes the prime objective of sampling analysis (Agresti and Finlay, 2009). In such analysis, stratified, proportionate, and two-stage cluster techniques could be employed (Kothari, 2004). This kind of probability sampling technique is a reasonable choice in a situation where researchers face financial and time constraint to access all villages across the study site (Del Casino, 2009). In two stage clusters sampling, in the first place, the larger study site (the study population) has to be stratified into appropriate size of sample units (clusters and sub-clusters) based on the purpose of the study. The sample units may be selected purposely or randomly depending on the nature of the study. Then after, sampling frame was organized for each of the selected sub-cluster. Finally, participants (individual sample HDs) in each of the selected sub-cluster may be selected in a random basis (Dawson, 2009). Clusters can be a larger geographical area like AEZs in a given watershed, whereas sub-clusters can be micro-watersheds or villages in a given AEZ. As part of minimizing the degree of systematic error to be committed in selecting sample HDs, employing more number of samples than what would be considered in non-cluster sampling is recommended (Dawson, 2009). Sample size may be determined using an equation or a rule of thumb (considering 10-20% of the sampling frame). The former technique of sample size determination can be employed only if statistical information like variance of the study population is available. A study population with a larger variance usually requires a bigger sample size (Kothari, 2004). In the latter technique of sample size determination, the proportion of sample size may be estimated based on a preliminary information to be generated employing FGD. This proportion was decided by looking at the overall homogeneity of socioeconomic and biophysical components (Taylor and Bogdan, 1998). Because of the absence of statistical report such as variance of the study population about the Jema watershed, this study followed the latter technique of sample size determination.

Following the sampling procedure indicated above, firstly, the study watershed was stratified into four AEZs (Figure 3.1). Secondly, a sub-total of 29, 14, 9, and 2 sub-clusters (micro-catchments/villages) were identified in the Moist-Cool, Cold, Moist-Cold and Sub-Alphine AEZs respectively. These clustering and sub-clustering were analyzed with the support of local development agents (DAs) and DEM. The number of selected micro-catchments was proportional to the geographical area of the clusters/AEZs. Thirdly, one third of the total number of sub-cluster was selected purposely, i.e., 10, 5, 3, and 1 sub-clusters in the Moist-Cool, Cold, Moist-Cold and Sub-Alphine AEZs respectively. Purposive sampling enables to select sample villages situated in various geographical sites. Fourthly, after collecting the list of HDs (sample frame) from the selected sub-clusters, 223, 114, 49, and 13 sample HDs were selected randomly (Annex 3.3). These sub-total HD sample sizes represent for Moist-Cool, Cold, Moist-Cold and Sup-Alphine AEZs respectively. The indicated sample size selected in each sub-cluster was ~30 % of their sampling frame (Annex 3.4). Out of the total 400 sample HDs in the entire Jema watershed, 88 % (352 HDs) was male headed, whereas 12 % (48 HDs) were female headed. District wise, 67.75%, 23.75% and 8.5% of the sample HDs fell in Mecha, Sekela and Quarit. This cross-sectional survey was conducted in late 2014 with the help of local development agents trained in the selection of households, timing and manner of conducting the survey and data recording. Moreover, verbal consent was obtained from each head of the sample households to make the research ethical.

3.4.2 Spatio-Temporal Variability of Climate

As part of investigating spatial differences in exposure to climate variability, this sub-section deals with the methods of analyzing the inter-annual variability of the average ATRF, the average MTmax and MTmin, onset and end dates of rainy season, and duration of the main rainy season. Furthermore, it discusses how the spatial interpolation analysis was made to the annual total RF.

Climatic Data Sets

As shown from the NMA meteorological data set that was accessed in 2014, the inconsistency data record was big challenge for running climate variability analysis. The problem was more serious in class 4 and 3 meteorological stations which were situated in rural villages and towns (NMA, 2014). To minimize the degree of error in the records of meteorological (RF in ^{0}C and Temp in mm) data sets, the Ethiopian Meteorological Agency in collaboration with International Research Institute for Climate and Society at Columbia University, USA, has reconstructed the incomplete meteorological data sets using meteorological satellite[28] records; whereas the data calibration and validation were undertaken by Reading University, UK (NMA cited at Mengistu, et al., 2014). This reconstruction was gridded data at a spatial scale of 10 X 10 km, and made for the years from 1983 to 2010. With regard to the quality of reconstructed data set, results showed a strong correlation (i.e., r =0.8) between the station and satellite-derived data. Accordingly, the average ATRF and MTmax and MTmin data sets of this study were collected from the estimated data sets (NMA cited at Mengistu, et al., 2014).

Spatio-Temporal Variability of RF and Temp

To compare the inter-annual spatial variability of the average ATRF, and MTmax and MTmin among the AEZs of the watershed, SD was computed. Hahn et al. (2009) recommended the same statistical tool for comparative analysis of local climate variability. The temporal variability of these indicators was also subjected further statistical analysis, i.e., a spatial and temporal linear trend with the value of the coefficient of determination (R^2) and linear regression. Gujarati et al. (2009) noted that R^2 is the square of correlation coefficient that indicates the proportion of the variance in the dependent variable that is predictable from the independent variable. R^2 values range from 0 to 1, with 1 representing a perfect fit between the data and the line drawn through them, and 0 representing no statistical correlation between the data and a line. The R^2 value (often referred to as the goodness of fit) is computed as follows:

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[28] Meteosat and NOAA (MODIS) satellite observations were used to reconstruct RF and Temp data sets respectively. The reconstruction of the satellite-derived data was done with the reference of observed data from 550 RF stations and 320 Temp stations throughout the country.

$$R^2 = 1 - \frac{\sum (Yi - Yi')^2}{\sum \left(Yi - \bar{Y}\right)^2}$$

Where, Y_i represents an individual data point value, Y_i' represents the value obtained by when the independent coordinate of this data point is input into the best-fit function (a line in this case). Therefore, Y_i' represents the values of the data points projected onto the line of best fit (the *ideal* values). $\hat{Y}$ represents the average of the Y_i values.

The detail on linear regression is stated under section 3.2.3.3 *"Spatial Variability of Soil Texture"*. Moreover, farmers' perception on climate variability was analyzed using the data generated from FGD. Ultimately, the result generated from the statistical analysis of meteorological data set was triangulated with farmers' perception (FGD data) on the variability.

Spatial Variability of RF

The spatial variability of the average ATRF among the AEZs of the watershed was analyzed employing the most appropriate geospatial interpolation method. In the analysis, the annual total RF (mm) data set was a predictand variable, where as elevation (meter) data set generated from the DEM 30m resolution was an auxiliary variable. As part of method of interpolation analysis, geostatistical functions and their performance are explored as follows:

Exploring Geostatistical Functions

Geospatial interpolation method can be used to characterize patterns of RF over various spatial scales provided that the data are abundant and spatially dependent (Li and Heap, 2011).The method is more appropriate when the data set exhibits smooth and consistent pattern of spatial dependence within the study area (Mohammad, et al., 2010; Webster and Oliver, 2007). As part of exploring the geostatistical function, spatial autocorrelation needs to be assessed applying semivariogram function. This function is defined in Equation 3.1. If two locations, s_1 and s_2, are close to each other in terms of the distance measure of $d(s_1, s_2)$, you expect them to be similar, so the difference in their values, $Z(s_1) - Z(s_2)$, would be small. As s_1 and s_2 get farther apart, they become less similar, so the difference in their values, $Z(s_1) - Z(s_2)$, will become larger.

Equation 3. 1. Semivariogram

$\gamma(s_1,s_2) = ½ \text{ var } (Z(s_1) - Z(s_2)$

Where, *var* is the variance; s=the observed location in terms of distance (d); Z= the observed value of a given variable situated in a given location (geographical distance).

The lag size (spatial distance) to be determined in modeling semivariogram can affect the value of sill[29], nugget[30], partial sill[31], range[32] (Figure 3.2), and ultimately the performance of the whole interpolation model. In larger lag size, possible short range spatial autocorrelation may be masked (Li and Heap, 2011). In the process of

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[29] Sill refers to the value that the semivariogram model attains at the range.
[30] The nugget effect can be attributed to measurement errors or spatial sources of variation at distances smaller than the sampling interval or both.
[31] The partial sill is the sill minus the nugget.
[32] Range refers to the distance value where the model first flattens out.

deciding the lag size, if the range of the fitted semivariogram model is very small relative to the extent of the empirical semivariogram, the lag size needs to be minimized. Conversely, if the range of the fitted semivariogram model is large relative to the extent of the empirical semivariogram, the lag size needs to be maximized. Depending on how well they fit the data, several semivariogram models (exponential, gaussian, circular, and spherical) may be employed (Jarvis, 2008). As a rule, a semivariogram model that fits to empirical data should pass as closely as possible to the mean values (blue crosses), and/or it should pass to the center of the cloud of binned value (red dots), and/or it should pass as closely as possible to the lines (green lines). The steeper the curves near the origin of the graph, the more influence the closest neighbors will have on the prediction (ESRI, 2014; Wackernagel, 2003).

Moreover, the performance of circular versus spherical function; exact versus inexact smoothing; and local versus global trend geostatistical functions were examined in the study. Spherical (directional effect) function is expected to be appropriate for interpolating environmental variables that show directional variability (Wackernagel, 2003). But still, the geographical scale of analysis, degree of variability of predictor variables, and the existence of multiple geospatial features like exponential and non-linear variation, global and local trends could reverse the result (Li and Heap, 2011). For example, local trend performs better in a situation where local variability (multiple trends) exists (Webster and Oliver, 2007).

OK (Ordinary Kriging), SK (Simple Kriging), UK (Universal Kriging), DK (Disjunctive Kriging), OCK (Ordinary Cokriging), IDW (Inverse Distance Weighting) , GPI (Global Polynomial Interpolation), LPI (Local Polynomial

Interpolation), and RBF (Radial Basis Function) were the interpolation models examined in the study. The models were run with the help of ArcMap 10.2 software (ESRI, 2014). The first five models are stochastic whereas the last four models are deterministic in nature (ESRI, 2014). Unlike deterministic methods, stochastic (kriging and Cokriging) interpolation methods can take into account the values of available relevant auxiliary variables for estimating values of a given predictand variable. These methods merit to analyze several error terms. Furthermore, it is only in stochastic methods that both accuracy and precision of predictions can be analyzed (Li, 2008; Webster and Oliver, 2007).

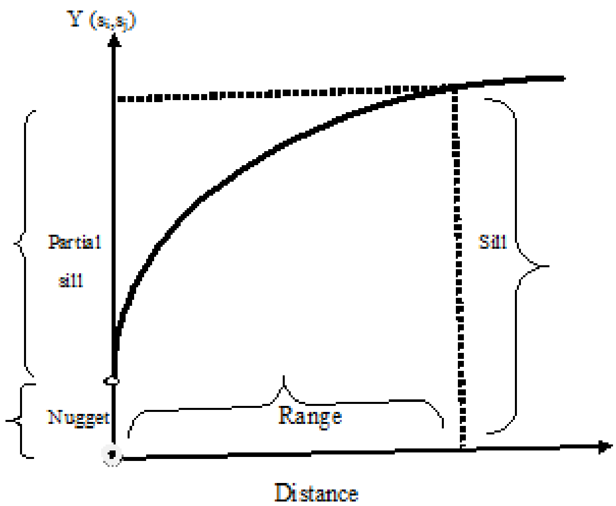

Figure 3. 2. Attributes of a semivariogram model

Evaluating Models' Performance

The models were evaluated by comparing possible committed error values (mean error, root mean square error, mean standardized error, root mean square standardized error and mean standard error) (EQ 3.2: A, B, C, D, E). The evaluation was made applying leave-one-out cross validation[33] geostatistical technique, at the 95% confidence intervals, in the ArcMap. In general terms, the best model is the one that has the smallest root mean squared prediction error, the mean standard error nearest to the root mean squared prediction error, the standardized mean nearest to zero, and the standardized root mean squared prediction error nearest to one (ESRI, 2014; Li, 2008). The first two criteria are used to identify the most optimal model, whereas the other two are used to identify the most valid model. These geostatistical methods have been used in several scientific studies (Robinson and Metternicht, 2006; Setegn, et al., 2009; Mohammad, et al., 2010).

Equation 3. 2 (A, B, C, D & E). Mean Errors

(A) $$ME = \frac{1}{n}\sum_{i=1}^{n}(p_i - o_i)$$ (B) $$RMSE = [\frac{1}{n}\sum_{i=1}^{n}(p_i - o_i)^2]^{1/2}$$ (C) $$MSE2 = \frac{1}{n}\sum_{i=1}^{n}(p_{si} - o_{si})$$

(D) $$RMSSE = [\frac{1}{n}\sum_{i=1}^{n}(p_{si} - o_{si})^2]^{1/2}$$ (E) $$ASE = [\frac{1}{n}\sum_{i=1}^{n}(p_i - (\sum_{i=1}^{n} p_i)/n)^2]^{1/2}$$

Where, ME=Mean Error; RMSE: Root Mean Square Error; MSE: Mean Standardized Error; RMSSE: Root-Mean-Square Standardized Error; ASE: Mean Standard Error; n=number observations or samples; o=observed value at place i; p=predicted/estimated value at place i;osi= standardized observed value at place i; psi=standardized predicted/estim ated value at place i.

3.4.3 Spatial Variability of soil Texture

In this sub-section, as part of investigating land capability and agroecosystem sensitivity to climate variability, the materials and methods employed for data collection and analysis of soil texture is discussed.

Soil Survey

[33] Leave-one-out cross validation uses all of the data to estimate the trend and autocorrelation models. It removes each data location, one at a time, and predicts the associated data value.

Soil sample sites and points were selected based on a two stage cluster sampling technique accompanied with a stratified and proportionate sampling procedure. The sample strata were prepared considering elevation and slope class variation of farmlands in the Jema watershed. Four elevation and seven slope sample strata were identified. Both the watershed boundary and the terrain class maps (raster layers) were delineated from satellite imagery, SRTM-DEM 30m resolution (Figure 3.3). The accuracy of the map (DEM data) was verified by a ground truth field survey data collected by using Garmin GPS with an accuracy of 3 meter error. Once elevation and slope classes (the sample units or clusters) were identified, the specific farmland sample sites and points in each sample unit (that were assumed homogenous in terms of biophysical setup) soil were chosen depending on their accessibility.

Hand auger and core sampler were used to collect sample soils. At every sample point, the geographic coordinates, slope (%) and elevation (m) records were taken from GPS. The soil sample was collected in the dry[34] season, after crop harvesting. For testing soil texture, 36 composite (and disturbed) samples were collected from 36 farmland sites (sample units) situated in the stratified slope and elevation classes (Table 3.2 and Figure 3.4). Each farmland site covers an area[35] of ~12.7 km^2. 1 composite (and disturbed) soil sample was collected from 3 to 4 discrete sample points in the same sample site. In some steep slope sites, it was difficult to get the top soil. Thus, to homogenize the soil horizon where samples need to be taken, the samples for texture analysis were collected at a

[34] Dry season refers to winter (*Bega)* season that stays from December to February.
[35] The average spatial **area** coverage of each sample unit (farmland site) where1 composite sample was collected. The scale of the map is categorized under large scale map (i.e., 1cm to 2km or 1:2000).

depth of 0-60cm. At this point, it is important to take into account that this analysis was done as part of agroecosystem sensitivity analysis.

With regard to bulk density (t/m^3), 3 to 4 discrete core samples were taken in each of the 36 sample sites indicated above. That is, a total of 90 discrete core samples were collected in the 36 sample sites. The methods, materials and procedures of sampling were adapted from Andrews and Carroll (2001); Landon, et al. (2014).

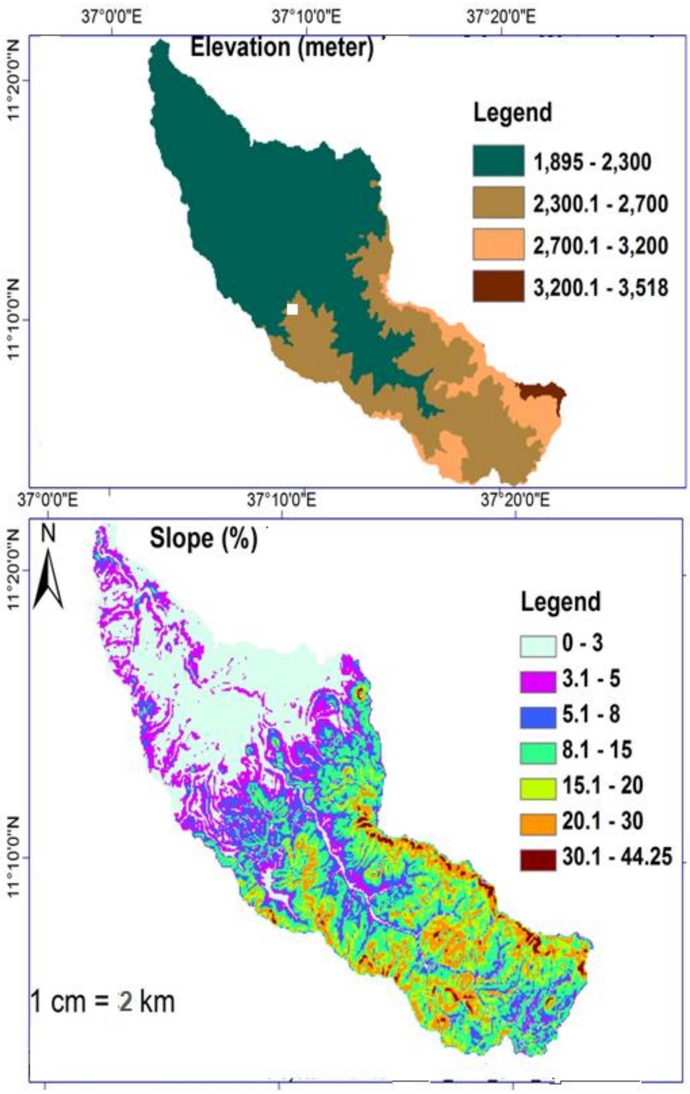

Figure 3. 3. Elevation (m) and slope (%) classes of the Jema watershed

	Elevation (meter)	Slope (%)	Latitude (degree)	Longitude (degree)
1.	1898	1.5	11.274654	37.134421
2.	2087	1.5	11.280303	37.125707
3.	2038	1.5	11.230848	37.189459
4.	2151	1.5	11.226823	37.194177
5.	2030	5.5	11.231123	37.193297
6.	2110	5.5	11.23583	37.137224
7.	2064	5.5	11.219977	37.144666
8.	2176	5.5	11.214671	37.145693
9.	2100	9	11.282037	37.214334
10.	2103	9	11.282394	37.211706
11.	2121	12.5	11.28824	37.067562
12.	2108	12.5	11.287309	37.068638
13.	2349	1.5	11.074602	37.292689
14.	2431	5.5	11.074158	37.292939
15.	2342	5.5	11.071633	37.300552
16.	2439	9	11.072688	37.301308
17.	2384	9	11.076579	37.282852
18.	2576	12.5	11.068713	37.324263
19.	2341	12.5	11.071278	37.326793
20.	2418	12.5	11.07225	37.326212
21.	2343	17.5	11.07262	37.325238
22.	2551	17.5	11.078302	37.345405
23.	2434	17.5	11.064183	37.33578
24.	2374	25	11.118761	37.387616
25.	2542	25	11.119908	37.387627
26.	2485	35	11.12394	37.385364
27.	2700	5.5	11.122808	37.382388
28.	2715	9	11.098898	37.37982
29.	2721	12.5	11.139684	37.15484
30.	2974	17.5	11.144396	37.155522
31.	2744	25	11.144395	37.155521
32.	2709	35	11.145239	37.155671
33.	3416	5.5	11.145195	37.156141
34.	3380	12.5	11.218014	37.239191
35.	3446	12.5	11.215008	37.23627
36.	3458	25	11.217313	37.235528

Table 3. 2. Soil sample points with their location and topographic profiles

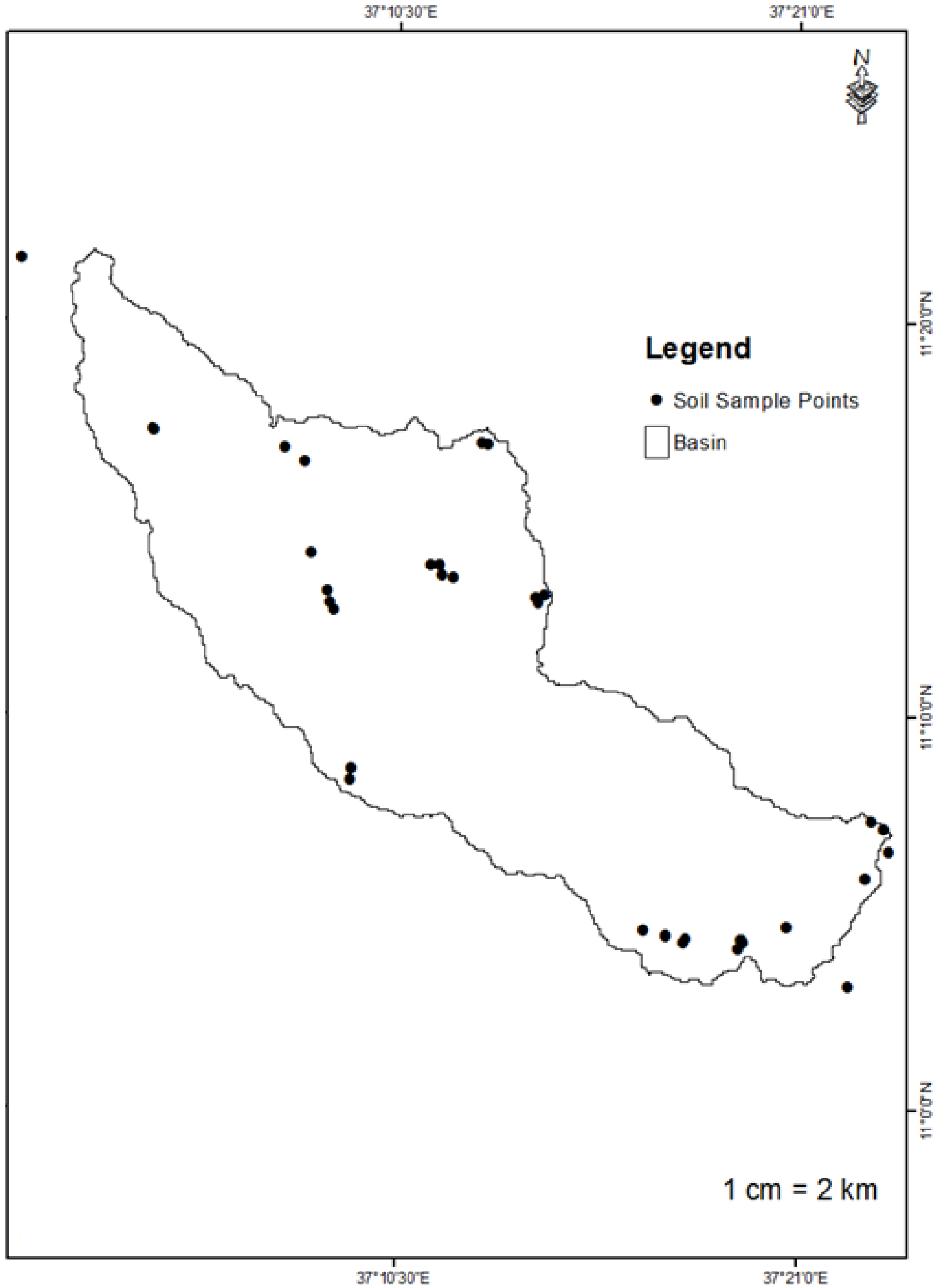

Figure 3. 4. Soil sample distribution in the Jema watershed

Soil Laboratory Analysis

The samples were analyzed in Bahir Dar Regional Soil Laboratory following the procedure of ISRIC (ISRIC, 2002). Bulk density (t/m^3) was examined from undisturbed samples after drying at 105^0C to a constant Temp for 24 hours. Texture was determined from the disturbed soil samples collected at the depth of 0 to 60 cm. The texture samples were then dried in the oven and sieved through a 2 mm sieve. For data validation, the association of bulk density (t/m^3) with terrain and soil texture (proportion of sand and clay) was tested using linear regression (EQ 3.3).

Equation 3. 3 Linear regression

$$Y=\beta_0 + \beta_1 X_1 + \beta_i X_i + U_i$$

Where, Y is an explained/dependent variable; β (β_0 and β_1) is vector of parameters to be estimated; β_0 is an intercept –an estimate of the amount (value) of dependent variable without any change in determinant variable; β_1 is a slope coefficient- an estimate of the amount (value) of change on dependent variable when explanatory variable increases by one unit; X_1 is an explanatory/determinant variable; and U_i is a random variable (an estimate of errors) that may occur for various reasons.

Different from ANOVA, linear regression is not a robust model if some assumptions are violated[36]. When one comes across a linear regression analysis report with unexpected error, it would be essential to check primarily the linearity and normality of the data sets (Kothari, 2004; Wooldridge, 2003). Hence, in order to run linear regression to various sections of this study, it was essential to be aware of (and assess) the following requirements: 1) The presence of linear (one directional) relationship between the dependent and independent variables. It can be assessed employing lack of fit test. When H_0 that states *"linear regression model is appropriate"* is not rejected (i.e., P >0.05), the assumption of linearity is satisfied. If a problem of linearity happens, one has to go back to the data set and settle the required amendments by following essential procedures. The other option would be using non-linear models depending on the nature and requirement of the analysis. 2) The presence of normal distribution in each of the

[36] When we violate an assumption, it usually means that there is a pattern to the data that we have not included in our model, and we could actually find a model that fits the data better.

data sets to be considered in the analysis. It can be tested employing statistics like skewness. As the value of skewness gets closer to zero, the normality of data distribution gets higher. If the problem of normality happens, it may be essential to take measures like log transformation.

In some other cases of linear regression analysis, it may be mandatory to go beyond linearity and normality assumption tests. That is, homogeneity of variance and multicolliniarity exploratory statistics may be required (Gujarati et al., 2009). Homogeneity of variance between two data sets can be tested employing F-test statistics. For this test, the null hypothesis is that variances of the individual cells are equal. When the null hypothesis is rejected (i.e., p-value <0.05), the variances are unequal, and the assumption is not met for linear regression. With regard to multicolliniarity, the test can be made by employing Pearson correlation coefficient (r^2) between two independent variables. There is a general agreement that the result with high correlation coefficient- r^2 value nearer to 1 or -1 (i.e., > 0.7 or < -0.7) may cause for colliniarity. This case may be solved by taking necessary measures like identifying and avoiding (or replacing with other appropriate records to be collected from the study site) overlapping records between independent variables that may cause for colliniarity.

As per the suggestion of similar studies that were conducted on livelihood vulnerability to climate variability (Deressa et al., 2009; Simane et al., 2014), all the inferential statistical analyses of this reseach were analyzed at 95% confidence interval. Moreover, the method of choosing estimates of the parameters (βs) in the linear regression analyses of this study was ordinary least squares (OLS).

Spatial Interpolation of Soil Texture

Kriking (OK, SK, UK and DK) and Cokriging (OCK, SCK, UCK and DCK) stochastic interpolation methods are tested in the study. The methods are selected because they consider auxiliary variable (BD) for interpolating the dependent variable. Like the case of RF interpolation, geostatistical exploration techniques were used for better accuracy of the interpolation models. Moreover, for evaluating the performance of the interpolation models, the same statistical tool, technique and procedure that were employed in the case of the RF interpolation were used. Finally, the raster surfaces of sand, clay and silt soil textures are combined and mapped into appropriate soil texture classes to the entire watershed. This was done referring USDA's soil texture triangle (Figure 3.5).

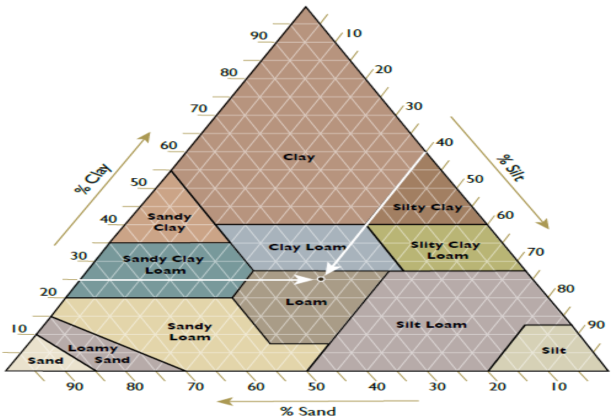

Figure 3. 5. Soil texture triangle adopted from USDA

3.4.4 Spatial Variability of Land use-Land Cover Types

As part of investigating agroecosystem sensitivity to climate variability, this sub-section presents the materials and methods used for creating a spatial data base of LULC.

Data Source (Material)

The features of satellite imagery employed for classifying LULC of the AEZs of Jema watershed was described in Table 3.3. The image was acquired at 2/1/2014 7:53:01 AM and accessed through United States Geological Survey (USGS) online data archive. This medium resolution image data was designed to meet both National Aeronautics and Space Administration (NASA) and USGS scientific and operational requirements for observing LULC change.

Path and raw number of the scene:	Path:170, and raw: 52
Number of bands (spectral resolution):	Out of 9 multispectral and 1 panchromatic band, RGB (4,3 & 2 band combinations) was used
Ground pixel size (spatial resolution):	30m resolution multispectral bands
Sensor's name:	Landsat 8
Products' name:	L1T
Cloud cover (%):	0.05
Reflectance bias:	-0.100000

Table 3. 3. Characteristics of the satellite imagery used for analyzing LULC classes

Training and Validation Data Sets

A total of 380 sample polygons were collected for seven land use/land cover classes in the four AEZs of the watershed. For sampling purpose, the proportion of LULC types was estimated by visual observation made with the help of global Google earth 7.1 imagery. Most of the samples were taken from grazing lands and cultivated lands. A Field visit to the sites was carried out to obtain both training (calibration) and validation data sets (Figure 3.6). This was made with the help of GPS. For remote corners, samples were taken from Google earth imagery. Nearly two third of the total sample were used for training purpose, i.e., for classifying the image into possible LULC types. The rest, 134 samples, were used for validating the classified image. In order to maximize the possibility of differentiating various land uses and land covers, Landsat8 and Google earth imageries scanned in dry season, in January 2014, were used. Furthermore, the training site polygons were generated carefully to avoid pixels located along the edges between LULC types.

Image Analysis

Two primary methods of image classification, supervised and unsupervised, have been known in image analysis (Janssen and Gore, 2001). In the former method, image interpreting software separates the pixels in an image based upon their reflectance values into classes or clusters without user defined. In supervised method, the analyst defines small areas, called training sample sites, on the image which are representative of each desired land cover category (Lillesand et al., 2014). As stated in the work of (Sabins, 1997), the delineation of training areas representatives of a cover type becomes more effective when an image analyst has knowledge of the geography of a region and experience with the spectral properties of the cover classes.

The LULC of this study was analyzed employing supervised classification method. It is recommended to employ this method especially in cases where the researcher has prior experience about the physical features of the site and could access the place for ground truthing (Bartholomé and Belward , 2005). It is observed in the LULC analysis of this study that the reflectance value of LULC types (like bare land versus farmland, houses versus fresh harvested land, grazing land versus bare land, streams versus houses) appear similar. Under supervised classification, maximum likelihood classifier tool has been the most recognized tool of image classification (Janssen and Gore, 2001). The classifier determines the variance and covariance of each theme providing the probability function.

This tool then classified an unknown pixel by calculating for each class, the probability that it lies in that class. The pixel was then assigned to the most class it is likened. This tool is incorporated in the ArcMap.

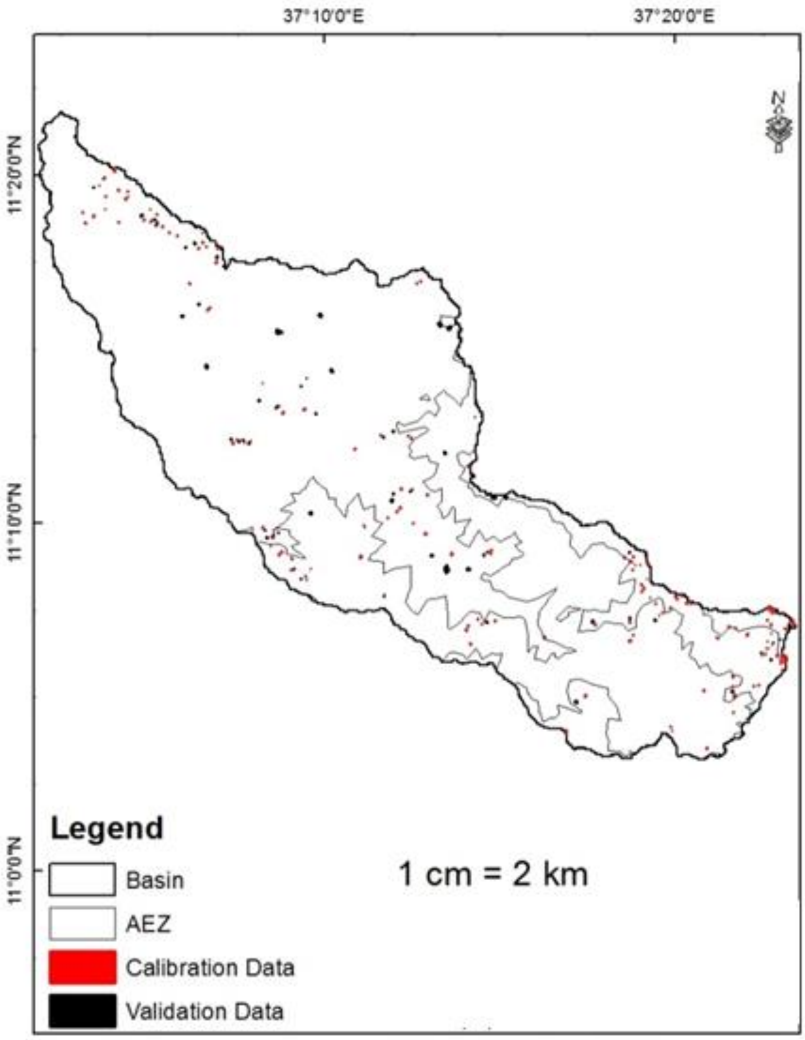

Figure 3. 6. The distribution of calibration and validation data sets for image classification

In the process of image analysis, first of all, the spatial reference of all data layers: Landsat8 30m r, watershed's boundary, sample polygons were projected into the same coordinate system, WGS_1984_UTM_Z_37. Since the image scanned to the study site at the specified date and time was free from visual problem, there was no need to do cosmetic enhancement.

Accuracy Assessment

Ultimately, the accuracy of LULC classification analysis was evaluated by computing confusion matrix (error matrix) to the calibrated and validated data sets and its Kappa statistic. It is supported by the work of Janssen and Gore (2001) and Bartholomé and Belward (2005). The confusion matrix was done by running pivot table in the ArcMap. Monserud (1990) suggested a kappa value of <40% as poor, 40–55% fair, 55–70% good, 70–85% very good and >85% as excellent. Depending on the purpose of the study, information in confusion matrix can be evaluated by referring values of overall accuracy, producer's accuracy, and/or user's accuracy (Jensen, 2005). Producer's accuracy gives the value of the proportion of sample points correctly classified into class X divided by the number of points observed to be class X, and reflects the accuracy of the model from the perspective of the model (Congalton and Green, 2009). This value is equivalent to model sensitivity, whereas user's accuracy gives the value of the proportion of sample points correctly classified into class X divided by the total number of points predicted to be class X, and reflects the accuracy of the model from the perspective of the model user (Congalton and Green, 2009). The number of correctly-classified sample points divided by the total number of sample points gives the value of overall accuracy. Teferi et al. (2013) have also used the same accuracy assessment method to analyze LULC dynamics in Jedeb Watershed, the upper Blue Nile River Basin.

Taking the statistical output of the confusion matrix, Kappa statistic was computed. It refers to the chance-corrected measure of model accuracy, based on the actual agreement between predicted and observed values and the chance agreement between the row and column totals for each classification (Congalton and Green 2009; Næsset, 1996). This statistic provides with insight into classification scheme and whether better results achieved than one would have achieved strictly by chance. The formula for kappa was given in EQ 3.4. The result of Kappa coefficient (K) ranges from -1 to 1.

Equation 3. 4. Kappa Coefficient

$$K= \frac{O-E}{1-E}$$

Where, K=Kappa coefficient; O=observed value of overall accuracy; and E= expected value calculated from the rows and column totals.

3.4.5 Spatial Variability of Land Capability Class

As part of investigating agroecosystem sensitivity to climate variability, this sub-section dealt with materials and methods employed for analyzing land capability classification. In order to identify the existing LCC, soil texture, slope and elevation and average ATRF limitations were considered. For all indicators (limitations), the same data sets (raster layers) generated for the section of soil texture analysis were used. Their degree of limitation and appropriate LCC was assigned by adapting USDA LCC guideline (Davidson, 1992; Young, 1972). That is, as indicated in Table 3.4, equal weight was given for all indicators. But still, different weight was attached to the diverse categories that fall in different LCC identified from the same indicator like the steepness of slope. In general, in the context of similar environment, as the slope of farmland increases, the limitation of land also increase (FAO, 2006). On the other hand, the limitation of land increases with elevation especially in the case of Ethiopian highlands that ranges from Moist-Cool to Alphine (Hurni, 1998). This is reflected in terms of the observed cultivable crop diversity and LGP (Table 2.1). Based on the preliminary FGD conducted in the AEZs of Jema watershed, crop diversity declines as one move from the upstream to the downstream. With regard to

LGP, there is a positive spatial association with elevation. With respect to soil texture (Figure 3.5), it is proved that as more proportion of soil particles gets away (i.e., in both directions) from loam[37] texture, the degree of limitation of land increases (FAO, 2006). Moreover, together with the incoming solar radiation to be received on the surface of the earth differences in the average ATRF that is received in cropping season may create variation in terms of crop type and diversity to be adapted, and water harvesting potential (Hurni, 1998). Hence, based on the amount of average ATRF, Wet, Moist and Dry zones are the three major categories recognized in the climatic context of the country (Table 2.1).

Categories for slope (%), soil texture (%), mean annual total rainfall (mm) and elevation (m asl)	LCCs and their degree of limitation					
	I (0)	II (0.2)	III (0.4)	IV (0.6)	V (0.8)	VI (1)
Flat or almost flat (0-3)	x					
Gently sloping (3-8)		x				
Sloping (8-10 %)		x				
Moderately steep (10-15)			x			
Steep (15-20)			x			
Steep (20-30)				x		
Very steep (30-44.25)					x	
Heavy Clay				x		
Clay				x		
Clay Loam		x				
Wet (>1400 mm)	x					
Moist (900-1400 mm)		x				
Moist-Cool (1895-2300)	x					
Cold (2300-2700)		x				
Moist-Cold (2700-3200)			x			
Sub-Alpine (3200-3518)				x		

Adapted from Davidson (1992) and Young (1976)

Table 3. 4. Land capability classes (LCCs) and their degree of limitation

In order to produce one comprehensive LCC layer to the AEZs of the watershed, first it was essential to generate the same type of layers for soil, slope and elevation and

[37]In terms of textural class, loam soil is believed to be the most optimal for plant growth with respect to air, water, mineral and nutrient circulation, which is vital for plant-soil interaction.

average ATRF features separately. Then, the raster layers of the three indicators were combined using a balanced weight overlay technique. For identifying the land size categorized under non-arable land but used for cultivation, the existing land use/cover and LCC layers were overlaid. It was done using Map Algebra function in ArcMap. Finally, the results were presented in figures (map) and tables, and interpreted.

3.4.6 Livelihood Vulnerability to Climate Variability among the AEZs

In this sub-section, the method and statistical functions used for aggregating all the processed data sets into IPCC-LVI analysis are discussed. The details pertinent to this analysis are presented under the topic of statistical tests and LVI analysis.

Statistical tests

According to the suggestion of Wackernagel (2003), a data set with homogenous variance and normal distribution is more appropriate to run inferential statistics. Hence, to know whether the nature of data was appropriate for One-Way-ANOVA statistic, homogeneity of variance were tested employing F-test statistic. Moreover, normality of the data distribution was tested with skewness. Yet, unlike linear regression model, ANOVA is relatively robust to violations of these assumptions, provided the violations are not too severe (Wooldridge, 2003). The square of Pearsons product moment correlation coefficient (R^2) was computed to detect the presence of a spatial linear pattern in the degree of vulnerability and its factors across the AEZs of the watershed. Furthermore, ANOVA test was analyzed to test the degree of spatial variability in factors of vulnerability among the AEZs. R^2 and ANOVA were previously used in similar case studies conducted by Simane et al.

(2014). In line with the recommendation from similar empirical studies by Deressa et al. (2009), Hahn et al. (2009), Simane et al. (2014), all inferential statistics of this study were analyzed at the confidence interval of 95%.

Livelihood vulnerability index analysis

Different indicators of vulnerability profiles may be measured at different scales. Hence, it becomes necessary to standardize the measured values of all indicators. Basically, the effect of standardizing values (indices) is to convert the indicators to relative rather than absolute values. This aids comparability, and yet it is helpful to remember that the indices should be interpreted within the livelihood context of the study site, where even the relatively better-off are poor by international standards (Vincent, 2007).

With respect to attaching weight to indicators, there have been two approaches of analyzing LVI (Deressa et al., 2009). The first one assumes that even though each livelihood profile includes indicators with different features, all of them are considered equally important. Hence, all the identified indicators wereconsidered in the analysis and they were given equal weight. For example, IPCC-LVI adopted a balanced weighted mean approach where each indicator identified under each profile was assumed to contribute equally to the overall index (Hahn et al., 2009). But still, the value of each factor was computed using weighted mean method, i.e., by considering the number of indicators that were included under each profile. The same approach was used in the vulnerability studies of Hahn et al. (2009) and Simane, et al. (2014). In the second approach, assigning different weights is essential to avoid the uncertainty of equal weighting given the diversity of indicators used. There are techniques suggested to make up for the weight differences of indicators. These approaches include using expert judgment (Vincent, 2007; Kaly and Pratt, 2000) and principal component analysis (Cutter et al., 2000; Deressa, et al., 2009; Ti Easter, 1999). Basically, this study has employed the first method mainly because there was no a historical livelihood profile data base that could give a clue to drive a reasonable weight to various indicators of livelihood factors of livelihood vulnerability.

However, unlike indicators listed under most livelihood vulnerability profiles, indicators of livestock type, crop types and land capability classes were given weight based on Tropical Livestock Unit (TLU[38]) (Table 3.5), Local Crop Unit (LCU[39]) (Table 3.6), and USDA's agricultural land capability classification (Davidson, 1992) respectively. Since this study employed a balanced weighted mean method, all indicators identified under each livelihood profile were considered (i.e., rather than employing principal component analysis for reducing non-principal indicators) in the livelihood vulnerability index analysis. Moreover, unlike the approach that was employed in the work of Sullivan (2002), the weight of each profile was differentiated considering the number of indicators incorporated.

Livestock	TLU value
OX	0.700
Caw	0.700

[38]TLU (Tropical Livestock Unit) is generated by Jahnke et al. (1988) provides a convenient method for quantifying a wide range of different livestock types and sizes in a standardized manner. The data source was FAO (1986 and FA 1987).

[39] LCU (Local Crop Unit) is generated by this study considering the mean value of the most recent 3 years (2014, 2013 and 2012) local market price of local crops. It is believe to be a convenient method for quantifying a wide range of different crop types in a standardized manner to a given locality.

Heifer	0.700
Bull	0.700
Sheep and Goat	0.100
Mule	0.700
Horse	0.800
Asses (Donkey)	0.500
Chikens	0.010

Adopted from Jahnke (1988)

Crop	LCU value
Barley	0.697
Potato	0.373
Maize	0.447
Teff (Eragrostis)	1.209
Pea and bean	1.512
Nug (Guizotia Abyssinica)	1.427
Onion (red)	0.897

The primary filed survey (2014)

Table 3. 5. Local Crop Unit (LCU)

Table 3. 6. Tropical Livestock Unit (TLU)

Looking at the nature and direction of expected relationship between the indicators and vulnerability, some indicators' indexed value were subjected to further computation, i.e., crop diversity index. At this step, the indexed values of selected indicators were inverted to give the right direction of relationship with vulnerability.

The mathematical notation of Human Development Index-HDI (EQ 3.4) that may be used for standardizing various indicators of livelihood profiles is developed by UNDP (UNDP, 2007). As an indicator of the quality of life of a country, for example, life expectancy index is calculated as the ratio of the difference of the actual life expectancy and a pre-selected minimum, and the difference of predetermined maximum and minimum life expectancy. The maximum and minimum values used in generating standard (index) value can either be taken from the actual data ranges (Hahn et al., 2009) or they can be threshold values chosen according to the context and purpose of the index (UNDP, 2007). Unlike HDI method, and similar to vulnerability study of Hahn et al. (2009), and Simane, et al. (2014), this study took the actual minimum and maximum values observed in the cross sectional survey to standardize the values measured at different scales.

Equation 3. 5. Index Value

$$\text{Index}_{IA} = \frac{I_A - IW_{min}}{IW_{max} - IW_{min}}$$

Where, Index I_A= indexed/standard value of an indicator in an agroecological zone; I_A=the actual value of an indicator in an agroecological zone; $I_W$min=the actual minimum value of the same indicator at the entire watershed; and $I_W$max= the actual maximum value of the same indicator at the entire watershed.

Next to compute the indexed value of each indicator, the values were aggregated into profile categories using EQ 3.6.

Equation 3. 6. Weighted Mean Value

$$\mathbf{P_A} = \frac{\sum_{i=1}^{n} \mathbf{index_s A_i}}{\mathbf{n}}$$

Where, PA= a profile value in an agroecological zone; i= represents indicators value, indexed by i, that make up each profile value, and n is the number of indicators in each profile; and index_s Ai=indexes of all indicators value in an agroecological zone.

There have been two methods of aggregating indexed factors into a single value of livelihood vulnerability: IPCC-LVI (Hahn et al., 2009) and LVI (Sullivan, 2002). The LVI–IPCC diverges from the LVI where the major components are combined. That is, rather than merging the factors into vulnerability index at a single step (EQ 3.7), they were first combined according to the categorization scheme: exposure, sensitivity and adaptive capacity to climate variability, using the same function shown in EQ 3.7. Then after, LVI–IPCC computation (EQ 3.8) was followed. That is, vulnerability was calculated as the net effect of adaptive capacity, sensitivity, and exposure. In this relationship, larger net value indicates lesser vulnerability and vice versa. In this study, the latter one was adopted. The same method was also employed in the study of Deressa et al. (2009); Mohan and Sinha (2010), Simane et al. (2014), and Snover et al. (2007).

Equation 3. 7. Livelihood Vulnerability Index (LVI)

$$\mathbf{LVI_A} = \frac{\sum_{i=1}^{n} \mathbf{WP_i} \ \mathbf{P_{Ai}}}{\sum_{i=1}^{n} \mathbf{WP_i}}$$

Where, LVIA = livelihood vulnerability index for an agroecological zone; WPi= weight (count) of each profile; PAi= a profile value in each agroecological zone; that make up each profile value, i= represents profiles value, indexed by i that make up each factor value; and n is the number of indicators in each profile.

Equation 3. 8. IPCC-Livelihood Vulnerability Index (IPCC-LVI)

IPCC-LVI = (E-A)* S

Where, IPCC-LVI= the overall value of livelihood vulnerability to climate variability index; E=exposure to climate variability; A=adaptive capacity to climate variability; and S=agroecosystem sensitivity to climate variability.

Similarly, there are alternative notations that may be used to aggregate and come up with one aggregate value of livelihood vulnerability (EQ 3.9) (Deressa, et al., 2009). Moreover, related concept like disaster risk may be aggregated employing EQ 3.10 (UN/ISDR, 2007). In doing livelihood vulnerability studies, as far as the same equation is employed to the communities identified for the comparative analysis, the final index values may be computed employing either of the nations (EQ 3.8 or 3.9). It is important to note that, in both notations, there need to consider the number of indicators in computing the indexed value of each profile to be identified under each factor. The former equation has become more popular in the most contemporary livelihood vulnerability studies (Simane, et al., 2014). As indicated earlier in this chapter, this study has also employed EQ 3.8. In the case of notation that is coined for disaster risk analysis, the place of sensitivity is not clearly seen. Hence, it may make the task of indicator identification and its analysis more challenging.

Equation 3. 9. Vulnerability Index

V= (A) – (S + E)

Where, V= the overall value of livelihood vulnerability to climate variability index; E=exposure to climate variability; A=adaptive capacity to climate variability; and S=agroecosystem sensitivity to climate variability.

Equation 3. 10. Disaster Risk Index

Disaster Risk = (Hazard X Vulnerability)/Capacity

3.3 Summary of the Chapter

This study was conducted in the AEZs of Jema watershed, north-western highlands of Ethiopia. The elevation of the site ranges from 1895 to 3518 m asl. Its geographical area covers ~483 km2. The site covers Moist-Cool, Cold, Moist-Cold, and Sub-Alpine AEZs. Summer is the main rainy season. The major soil orders are Alisols, Nitisols and Vertisols. The livelihood of farmers was dependent on rainfed and subsistence agriculture. Food crop production, livestock rearing and daily labor were the major income sources.

For the socio-economic cross-sectional survey, a sample of 400 randomly selected HDs participated. The number of selected samples in each of the AEZ was nearly proportional to the size of their geographical area. Moreover, FGD was employed to generate historical data on climate variability. One FGD was made in each of the AEZ. In every FGD, there were 6 to 8 participants. Furthermore, pilot FGD was carried out to customize the contents of the structured questionnaire. For the physical (soil, climate, elevation, slope, LULC, land capability class) resources analyses, soil survey, meteorological record and satellite imagery were the major data sources. Finally, to make the spatial variability analysis among the AEZs, the data sets were aggregated into factors of vulnerability to climate variability: exposure, agroecosystem sensitivity and adaptive capacity to climate variability. The analysis was supported with trend line (R^2), One-Way-ANOVA and simple linear regression, and geostatistical tools). Ultimately, using LVI-IPCC function, the livelihood vulnerability to climate change was analyzed for each of the AEZs of the watershed. The result is presented in tables and figures.

Chapter Four

4. Results and Discussions

In this chapter result and discussion of the study are presented in six sub-sections. The topics are stated in line with the specific objectives of the study. The order of the presentation is as follows: 1^{st}) the spatio-temporal variability of climate, 2^{nd}) the spatial variability of soil texture, 3^{rd}) the spatial variability of LCC, 4^{th}) the spatial variability of LULC type, 5^{th}) the spatial variability of farmers' adaptive capacity, and 6^{th}) the spatial variability of livelihood vulnerability to climate variability among the AEZs of the Jema watershed. The observed adaptation strategies are also discussed in the 6^{th} section.

4.1 Spatio-Temporal Variability of Climate among the AEZs of Jema watershed

In this section, results and discussion on spatio-temporal analysis of RF and Temp are presented. The topics are discussed in four sub-sections. These include: surfacing the spatial distribution of the average ATRF, farmers' perception on climate variability, spatio-temporal variability of the average ATRF, and MTmax and MTmin among the AEZs, and the indexed values for the degree of climate variability in the AEZs of the watershed. Finally, a summary of the section is given.

4.1.1 Surfacing the Spatial Distribution of the Average ATRF

The preliminary analysis made for surfacing the spatial distribution of the average ATRF showed that the sample gauge stations considered for the interpolation were located in the north, south, east and west directions of the Jema watershed (Figure

4.1.1). The samples were situated approximately within the range of ~40 km radius from the center of the watershed. Accordingly, the overall observed situation was found appropriate for employing the geo-statistics and for surfacing the average ATRF to the entire watershed.

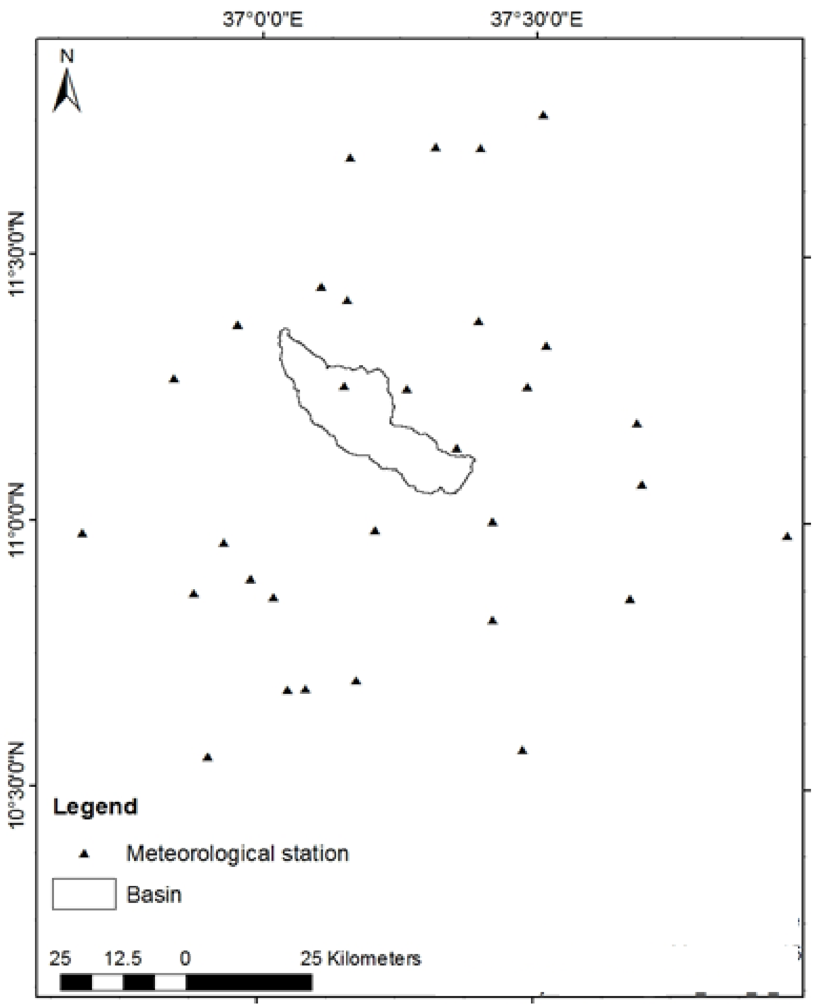

Figure 4.1.1. The distribution of sample meteorological stations

Screening Potential Interpolation Models

Initially, observing the existence of poor correlation between observed average ATRF value (as a predictand variable) and observed elevation value (as a covariable), it was planned to test only kriging methods. In this correlation analysis, at the spatial linear trend, the value of R^2 was -0.1 (Figure 4.1.2).

In the process of interpolating the predictand variable, specifically, neighborhood search analysis step, it was possible to detect a kind of average ATRF spatial pattern that follows elevation variation in some corners of the kriged surfaces (Figure 4.1.3). Accordingly, in addition to Kriging models, it was found reasonable to test Cokriging model.

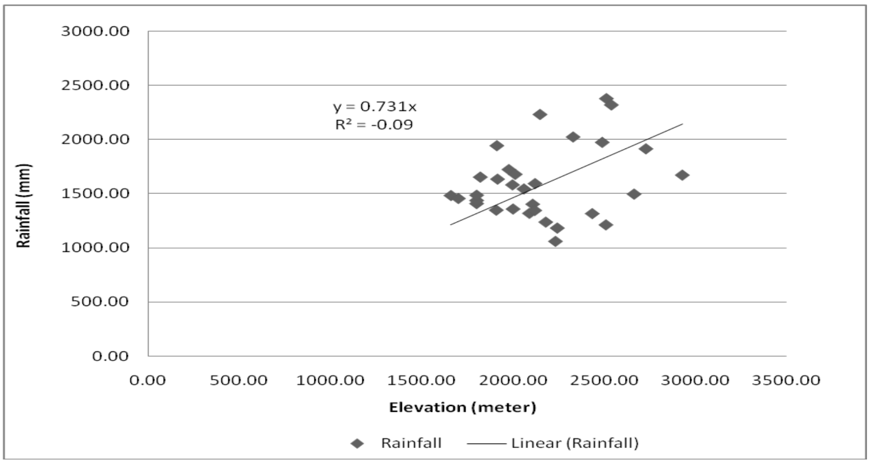

Figure 4.1. 2. ATRF versus elevation association

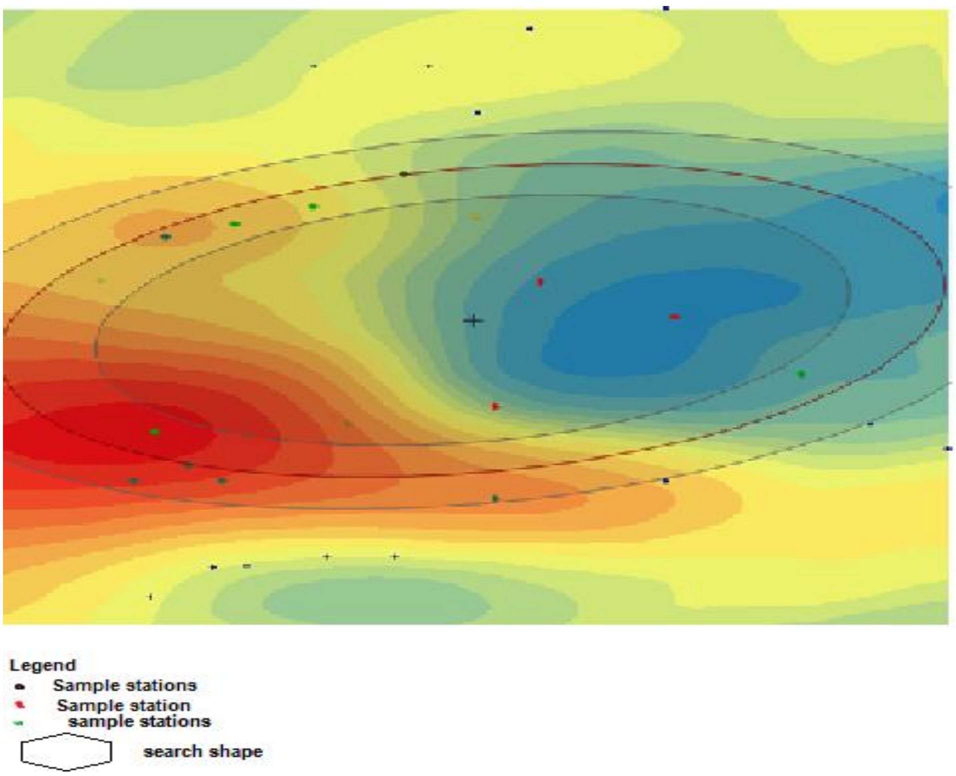

Figure 4.1.3. kriging (OK) interpolation with spherical search

Testing Geostatistical Autocorrelation

In the semivariogram modeling, stable and Gaussain model became the best fit to the spatial autocorrelation of the observed average ATRF data set. The model (trend line) passed through the binned value, and the mean values were distributed near the mode line (Figure 4.1.4). The analysis was done with 6 lags (the number of the blue crosses) having 20 km lag size each.

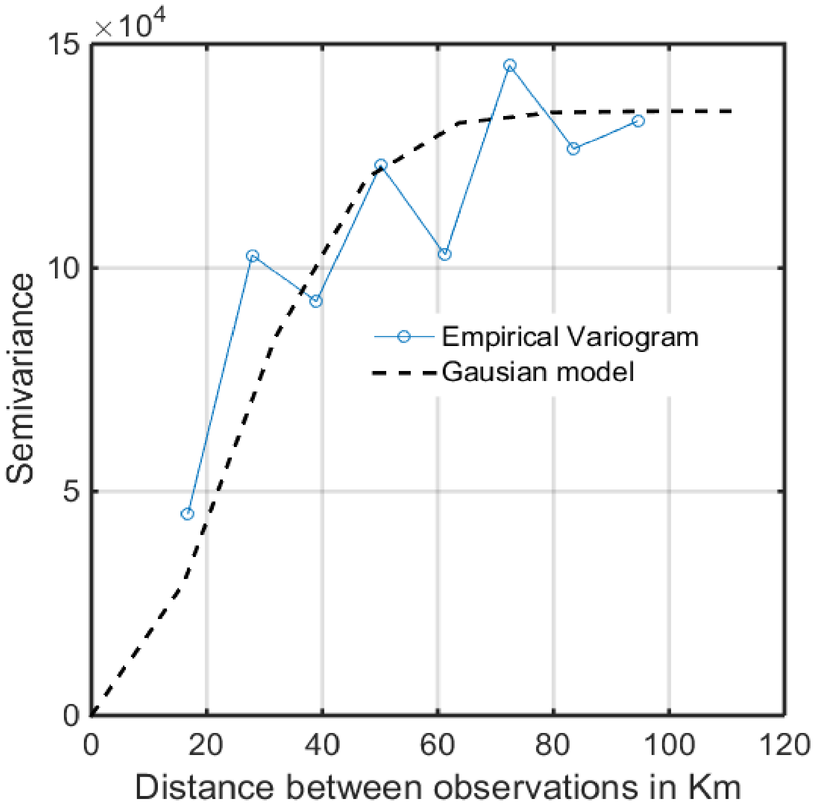

Figure 4.1. 4.Semivariogram model for the sample average ATRF data

Neighborhood Searching and Directional Influence

The interpolation model became effective with local polynomial type of trend removal (local variation), non-power function (non-weighted mean) and 6 to 2 maximum-minimum local neighbor searches. The sector type was found 4 with 45 degreees with a major range of 0.66 km towards south-east to north-west direction and a minor range of 0.28 km in north to south direction (Figure 4.1.5). In the geo-statistical analysis, anisotropy effect was identified with an elliptical shape of neighborhood search strategy (Figure 4.1.5). Figure 4.1.6 indicated that at the scale of the watershed, the amount of average ATRF declines significantly as we go from north-west south-east, i.e., from lower to higher elevation areas. However, in the entire sample site, there was weak correlation between the average ATRF and elevation (Figure 4.1.2).

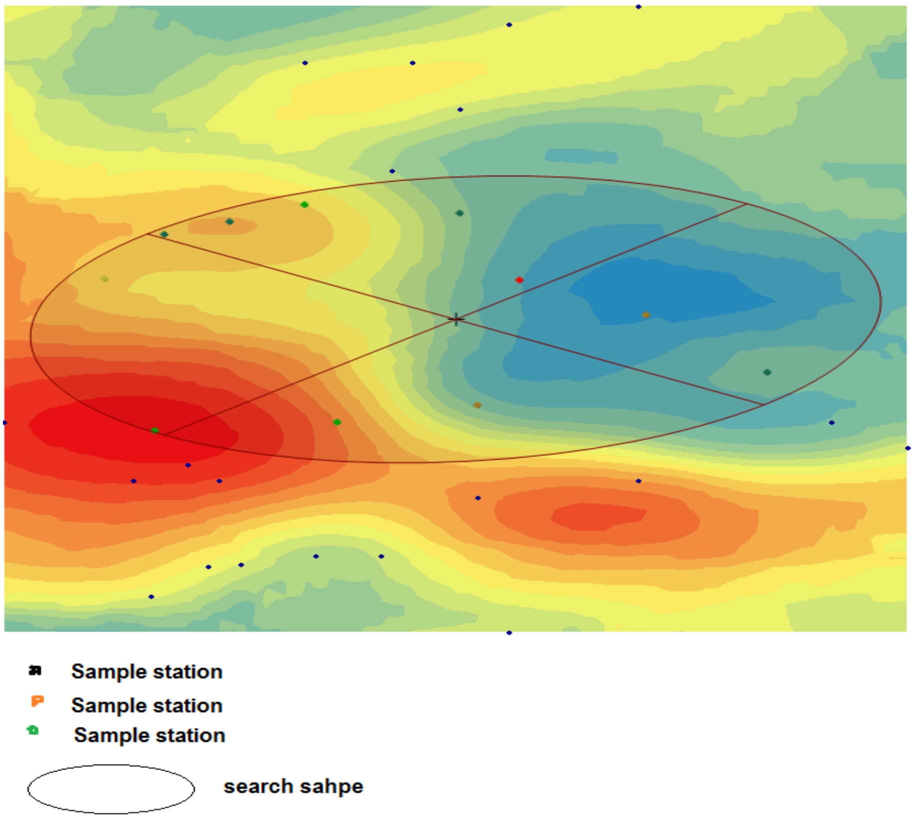

Figure 4.1. 5. Elliptical neighborhood search (OCK)

The result shows the existence of direction influence and non-linear smooth variation in the average ATRF distribution in the entire interpolated (sample) site. In the entire sample site, the estimated amount of the average ATRF increases as we go from north-west south-east (Figure 4.1.6 and 4.1.7). Similarly, in the case of the specified study watershed, the amount of the average ATRF declines in the same direction. Moreover, the same table shows the existence of a number of ups and downs in the values of the spatial distribution of the average ATRF in the whole sample site.

The finding indicated in Figure 4.1.6 implied that the Equatorial (South Easterlies) wind from Indian Ocean enhances the amount of ATRF to be received in the main rainy season (*Kiremt*) to the entire sample site, part of the north-western highlands. Accordingly, highlands in the West of the entire sample site are situated in wind ward side and receive relatively higher average ATRF.

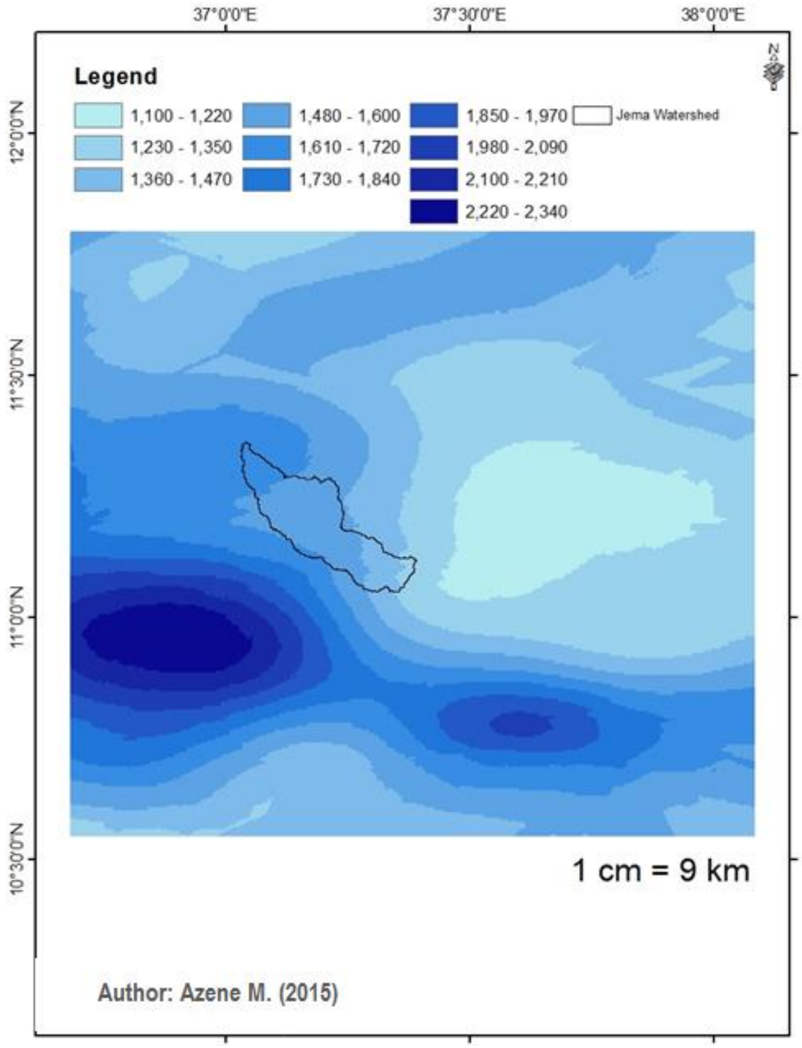

Figure 4.1. 6. Kriged value of the average ATRF (by OCK) for the entire interpolated surface

Similar to the finding of this study, Conway (2000), and Levin, et al. (2009) found out that the ATRF declines from west to east of the country. On the other hand, the finding of this study is contrary to the national observation by MOARD (2000) and Hurni (1998) in which the amount of average ATRF increased with elevation. This study shared the general conclusion of Hurni (1998) and MOARD (2000) that Ethiopian highland RF is relief in type. That is, in the distribution of the average ATRF, mountains create wind ward and lee ward side effect.

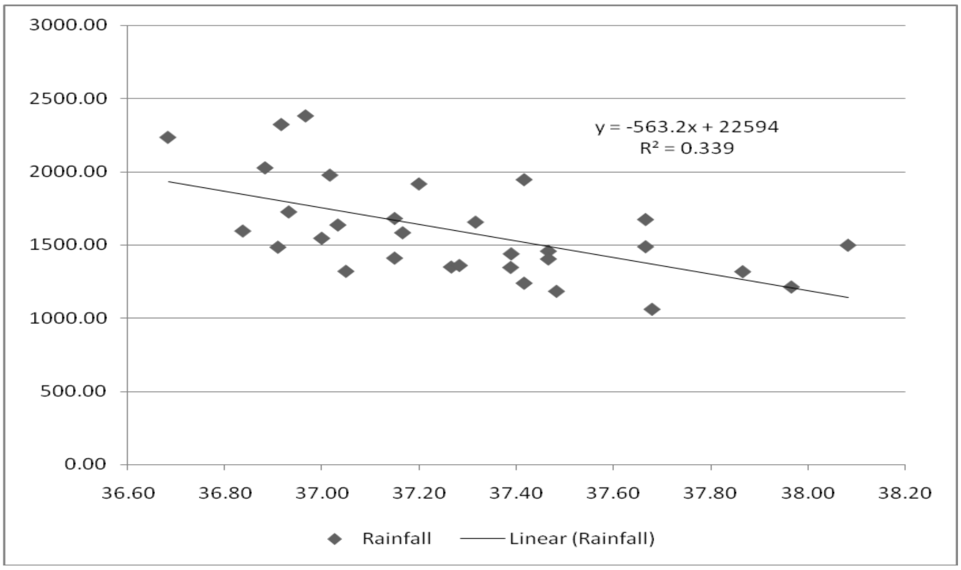

Figure 4.1.7. ATRF and longitude coordinates association

Evaluating Models' Performance

The least RMSE and the least range statistic in between RMSE and ASE were observed in the OCK model (Table 4.1.1). The predictive power of the model was 87.3% (Table 4.1.1 and Figure 4.1.8). Compared to the other models, OCK was found to be the most appropriate to the context of the study site. This model enhanced the predictive power of estimation in the range of 1.05% (15mm) to 11% (134mm). Furthermore, in the precision of measurements, the value of RMSS indicated that all models showed similar results. But still, OCK resulted in the best precision value (RMSE=0.72 mm) (Table 4.1.1).

Because of the presence of south-east to north-west spatial pattern in both average ATRF and elevation, topography contributed as a covariable for improving the performance of the multivariate geostatistical estimation techniques. This estimation was observed in a situation where the correlation between the average ATRF and longitude coordinate values was found at medium (R^2=0.43) level. Hence, in the process of choosing environmental covariables, in addition to the strength of correlation (R^2) between the predicted variable and covariable, one may need to look at the level of error to be indicated by nugget.

Furthermore, the spatial association that was not detected by simple non-geospatial correlation analysis (Figure 4.1.7) could be observed applying geostatistical analysis, kriging (Figure 4.1.3, 4.1.5 and 4.1.6). Based on the extracted kriged values, the study watershed receives 1228 mm to 1640 mm average ATRF (Figure 4.1.9). The amount of rainfall declines from north-west south-east.

Prediction Error Type	Model								
	DK	UK	SK	OK	IDW	GPI	LPI	RBF	OCK
ME	5.78	11.86	11.53	11.56	8.90	-2.42	-16.53	1.86	15.24
RMS	178.18	177.57	172.12	171.46	205.62	291.72	218.73	219.38	157.95
MS	0.01	62.36	0.03	0.03	*	*		*	0.04
RMSS	0.78	1.26	0.76	0.76	*	*		*	0.72
ASE	239.93	0.15	244.90	244.26	*	*		*	231.79

ME: Mean Error; RMS: Root Mean Square; MS: Mean Standardized, RMSS: RootMean Square Stan dardized; ASE: Mean Standard Error; DK: Disjunctive Kriking; SK: Simple Kriking;OK: Ordinary Kriki ng; IDW: Inverse Distance Weighting; GPI:Global Polynomial Interpolation; LPI: Local Polynomial Inte rpolation; RBF: Radial Basis Function; OCK: Ordinary Cokriging; .*: Not Applicable;

Table 4.1. 1. Cross-validation statistics computed for interpolation models to estimate the average Annual Total Rainfall (ATRF).

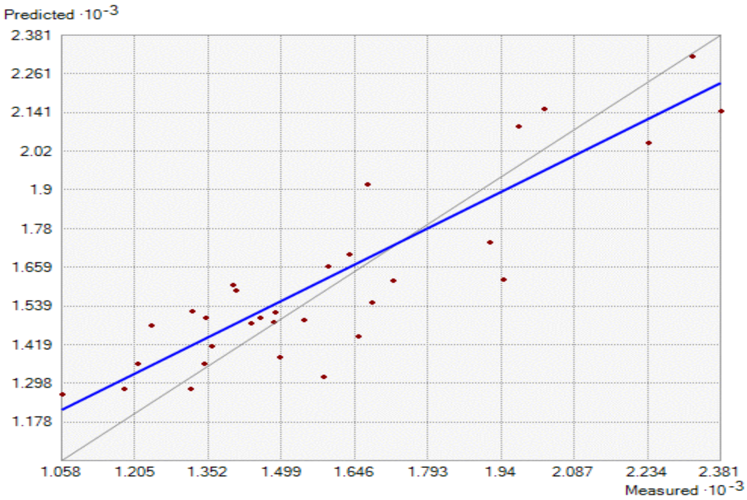

Figure 4.1. 8. Prediction error line graph for ATRF (OCK)

AEZ	Elevation (m)	ATRF (mm)	MTmax (°C)	MTmin (°C)
Moist-Cool	1895-2300	1640	26.53	10.33
Cold	2301-2700	1520	25.33	9.86
Moist-Cold	2701-3200	1400	23.12	7.52
Sub-Alphine	3201-3518	1310	21	4.7

Table 4.1.2. The kriged average values of ATRF and Temp in the AEZs of the Jema watershed

Finally, ANOVA has been used to test whether there is statistical difference in the values of the average ATRF, and MTmax and MTmin among the AEZs (Table 4.1.2). As shown in Table 4.1.3, the two-tailed P-value (0.038) < 0.05. Thus, H_0 (the null hypothesis stating no a significant variation among groups) was rejected. That is, there was a significant variation in the average ATRF among the AEZs of the watershed. The same was true for the MTmax and MTmin.

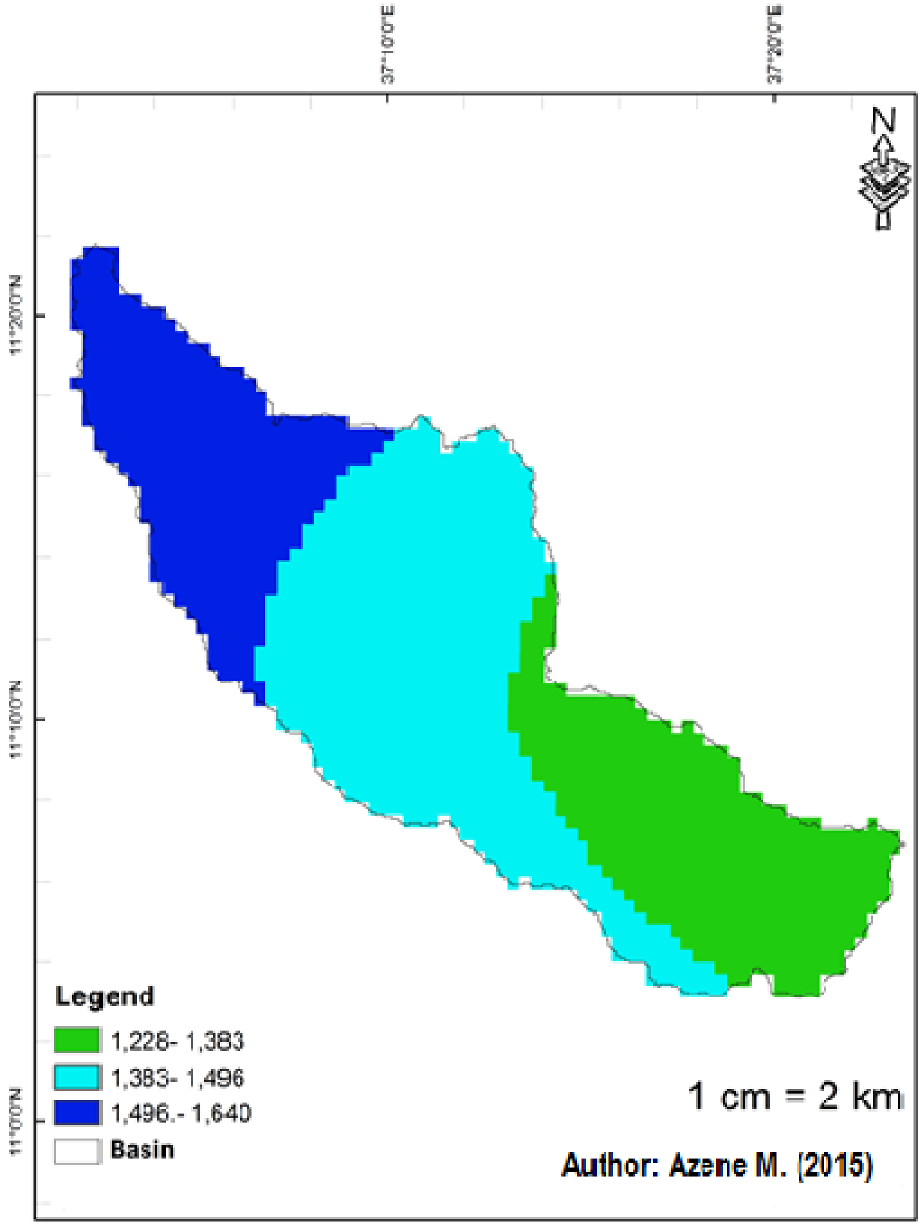

Figure 4.1. 9. The Kriged average values of ATRF in the elevation zones of the Jema watershed

Source of Variation	Dependent Variable	P-value
Between Groups	ATRF	0.04
	MTmax	0.01
	MTmin	0.04

Df=3

Table 4.1. 3. One-Way-ANOVA Single Factor result for the average ATRF, MTmax and MTmin among the AEZs.

Climatic studies (Li and Heap, 2011; Phillips, et al., 1992) showed different results in the performance of interpolation models. In the case of this study, Cokriging (specifically OCK) became superior over deterministic and kriging methods. That happened in a situation where there was variation in microclimatic condition. Elevation, as a covariable, has played a role in minimizing the estimation error. It was true in the absence of a statistical association between the predictand (the average ATRF) and the covariable (elevation).

Ethiopian rainfall occurs in summer and spring season that is mainly driven by the Westerly wind from the Atlantic Ocean and easterly wind from the Indian Ocean (Conway, 2000). The average ATRF over the basin decreases from the south-western to the north-eastern part of the country (Seleshi and Zanke, 2004). MOARD (2000) and Hurni (1998) indicated that the amount of the average ATRF of Ethiopia increases with elevation. Similar to the argument of Conway (2000) and in contrast to the general observation of MOARD (2000), the result of this study showed that the amount of ATRF declines from north-west south-east. It happened in a situation where elevation increases as one moves from north-west south-east. Nevertheless, the same pattern of mean ATRF was not observed all over the study corners that were included in the interpolated surfaces. The reason for the observed patterns of rainfall could be an interactive effect of the direction of moist wind movement and microclimate factors. Thus, in a river basin, where there is complex topography and wind convection system, accurate and precise mean ATRF estimation needs a larger scale (watershed) analysis rather than basin and sub-basin scales.

Overall, the average ATRF across the watershed ranges from 1228 mm to 1640 mm. The difference in the average ATRF was found significant among the study AEZs.

This range of mean ATRF fall dominantly under moist[40] and wet category. Hence, the study watershed may be categorized under Moist Highland adaptation planning zone. This categorization is made referring the previous studies (MOEF, 2011; Hurni, 1998).

The total moisture obtained from the rainwater dominantly in summer season can be considered adequate to grow a wide range of local annual crops including barley *(Hordeum Vulgare)*, wheat (*Triticum* Spp), *teff* (*Eragrostis)*, maize (*Zea Mays)*, finger millet (*Eleusine Coracana)*, sorghum (*Sorghum Bicolor)*, horse bean (*Vicia Faba*), pea (*Pisum* Sativum), lentil (Lens Esculenta), and potatoes (Solanum Tuberosum). And yet, the difference in the amount of Temp was important in determining the type of crop grown in the AEZs. In terms of total moisture obtained from the rainwater, the farming systems of the AEZs located in the lower elevation are more advantageous or less sensitive. This might be true with respect to rainwater harvesting potential that could be utilized as a backup for the time of unexpected shortage of rainwater in the same season. As stated in the document of PASDEP (MOFED, 2006), enhancing water harvesting and irrigation potential was a key priority in the agricultural sector for adapting climate stresses like RF variability and Temp change. It is important to note that for determining the availability of moisture in the soil for crop production, and categorizing the study site into moisture zone, there needs to be further information on spatio-temporal variability of the average ATRF, Temp, soil texture, slope, land use land cover and land management practices.

[40] A place that receives 900mm-1400mmrainfall is considered as moist, whereas <900mm is dry, and >1400 is wet (Hurni, 1998).

Unlike RF, there is no need to make interpolation analysis for Temp. It is clear that a variation in elevation causes differences in Temp and evapo-transpiration even for locations at similar latitudes. In the lower part of the atmosphere, on average, Temp decreases at ~6.4 °C/1000 m (Hurni, 1998). Because of the same reason, the elevated part of the watershed was Colder and experiences longer LGP.

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4.1.2 Farmers' Perception on Temporal Variability of RF and Temp

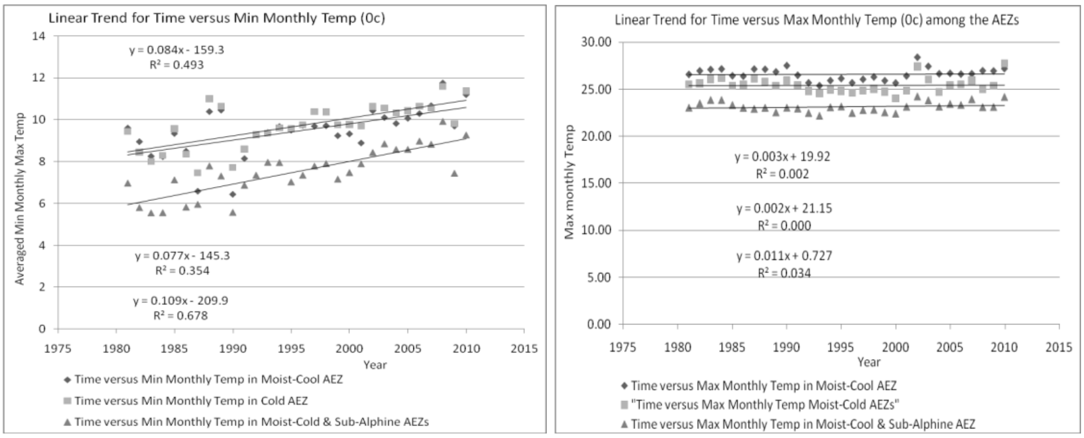
The FGDs conducted with farmers in all the AEZs of Jema watershed indicated that exposure to climate variability has been real. This had two manifestations: firstly, about 15 or 20 years before, all of the AEZs experienced a longer (summer) rainy season. In addition, there was a difference both in the onset and end datesof the rainy season. The rainy season lasted from the end of April to the end of November in *Sub-Alphine* and *Moist Cold* ; from the beginning of May to beginning of November in Cold; from the beginning of May to the end of October in *Moist Cool Highland* . Nevertheless, in the last 15 years, the onset of the RF season has been late by one month and two weeks in *Sub-Alphine* and *Moist Cold* areas, and one month late in *Cold* and *Moist Cool Highland* areas. Similarly, the end dateof rainy season has been early by one month and two weeks in *Sub-Alphine* and *Moist Cold* areas, and one month early in *Cold* and *Moist Cool* areas. Secondly, almost all farmers in all of the AEZs perceived a historical decline in the average ATRF. On the contrary, there was a rise in Temp. As a result, in *Sub-Alphine* AEZ (especially at the top most of Birr Adama Mountain), contrary to the situation noted about before 15 years, no accumulation of ice was observed in recent years.

4.1.3 The Spatio-Temporal Variability of Rainfall and Temperature

A temporal linear trend for the inter-annual variability of the average MTmax, MTmin, and the average ATRF among the AEZs is summarized in Figure 4.1.10 (A & B) and Figure 4.1.11 respectively. The averaged values of SD of these climatic variables to each AEZ are presented in Table 4.1.4. This table included a p-value of simple linear regression analysis that was made to test the association between time (year) and the same climatic variables in each of the AEZs.

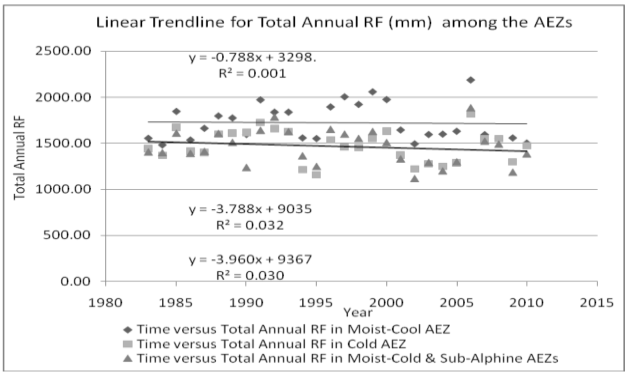
The value of inter-annual variability (SD) of the average ATRF, and the average MTmax and MTmin data sets were found to be different among the AEZs. Yet, the P-value is > 0.05 in all cases of RF and Temp analyses (Table 4.1.4). Moreover, in the temporal linear trend analysis of Temp (Figure 4.1.10: A and B) and RF (4.1.11) that was made in each of the AEZs, the value of R^2 was very poor. The slope (coefficient) of the linear regression line for the average ATRF (mm) per year was -7.89, -3.788 and -3.960 in Moist-Cool, Cold and Moist-Cold & Sub-Alphine AEZs respectively. The slope of the linear regression line for the mean monthly Temp (^{0}C) per year was 0.025, 0.034 and 0.049 to the AEZs in the same order respectively.

(A) (B)



NB: The order of the equations follows the order of the legend.

Figure 4.1.10 (A & B). A linear trend for the inter-annual variability of the mean MTmin and MTmax (^{0}C) in the agroecological zones (AEZs)



NB: The order of the equations follows the order of the legend.

Figure 4.1.11. A linear trend for the inter-annual variability of the mean Total Annual Rainfall (mm) in the agroecological zones (AEZs)

Parameters	AEZ								
	Moist-Cool			Cold			Moist-Cold & Sub-Alphine		
	Variable			Variable			Variable		
	ATRF	MTmax	MTmin	ATRF	MTmax	MTmin	ATRF	MTmax	MTmin
SD	155	2.61	1.89	145	2.74	1.76	133	2.86	1.59
P-value (linear regression)	0.87	0.96	0.57	0.36	0.55	0.24	0.38	0.82	0.03

Table 4.1. 4. The inter-annual variability (SD and P-value) for the average ATRF (mm), MTmax and MTmin (^{0}C) in the agroecological zones (AEZs)

The analysis of the study revealed that the amount of the average ATRF over years (1983-2010) did not show any trend in all the AEZs of the watershed. And yet, in the values of inter-annual variability of ATRF, this study proved the presence of increases and decreases over the years. As reported by MOEF (2014), rainfall at national level was subjected to high variability between years, seasons and regions. At national level, the yearly variation around mean rainfall levels was estimated to reach 25% and increase to 50% in some regions. A study by Mengistu (2014) conducted in the north- western part of the country showed a similar result. Verdin et al. (2005) and Conway (2000) also did not find any trend over the larger region of the Blue Nile River Basin. On the other hand, NMSA (2001) reported a declining trend in the northern and southern parts of the country. Furthermore, projections for precipitation were far more uncertain in the country in general (Solomon, 2007) and in the Blue Nile River Basin in particular (Zaitchik et al., 2012). The presence of different research outcomes in the topic imply the complexity of microclimates in the broader region where the study site was situated.

The slope of the trend lines for the mean monthly Temp (^{0}C) per decade was 0.25 (in Moist-Cool AEZ), 0.34 (in Cold AEZ) and 0.49 (in Moist-Cold and Sub-Alphine AEZs) of the Jema Watershed. Similarly, as stated by MOEF (2014), it was estimated that the temperature increased in the ranges of 0.1^{0}C to 0.4^{0}C per decade. The observed Temp rise in this study site was larger as compared to IPCC's global observation of mean Temp rise (0.74 ^{0}C) over the last century.

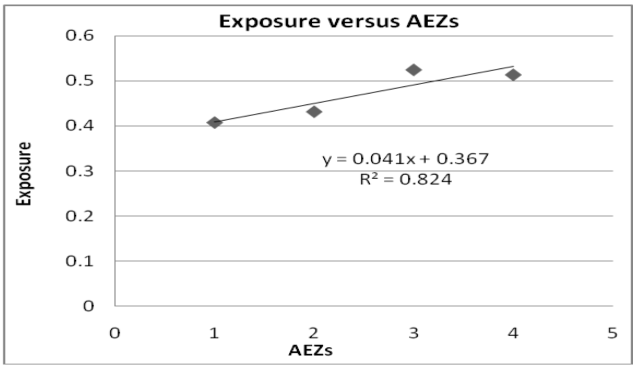
The output of FGD (farmers' perception) was in line with the results of meteorological (RF and Tem) inter-annual temporal variability analysis. These results were also in agreement with the previous climatic (RF and Temp) studies (Simane et al., 2014; Bewket, 2008) conducted in the north-western part of the country. The inter-annual variability of the average ATRF observed in the study area was attributed to El Niño. Korecha and Barnston (2007) explained that the inter-annual variability of

Ethiopia's June to September rainy season was governed primarily by El Niño–Southern Oscillation (ENSO), and secondarily reinforced by more local climate indicators near Africa, the Atlantic and Indian Oceans. In the recent years, i.e., 2015/2016, a strong El-Nino caused severe droughts and crop failure in Ethiopia during the whole rainy seasons of spring and summer (FAO and WFP, 2016).

Regarding the variability of duration of the rainy season, as indicated in the FGD, the degree of variation increased from north-west south-east. On the other hand, the meteorological data analysis of this study revealed that the variability (SD) of ATRF was lower in the eastern part than in the western part of the study watershed. But still, the inter-annual variability (SD) of the average ATRF was not statistically significant. The result of the variability (SD) was in agreement with the output of studies (Haile, et al., 2009; Mengistu, et al., 2014) conducted in the broader region where the study site is located.

4.1.4 The Indexed Values of Exposure to Climate Variability

For comparing the degree of exposure to climate variability among the AEZs, the results mentioned above were standardized and summarized in Table 4.1.5. This indexed value ranges from 0.424 to 0.600. The highest value was observed in the AEZs located in higher elevations. This value was found to be explained by a spatial linear trend with 0.82 R^2 value (Figure 4.1.12). On the other hand, as per the result of temporal linear regression analysis made for RF and Temp variables in each AEZ, no statistical association was observed (Table 4.1.4).



1=Moist-Cool, 2=Cold, 3=Moist-Cold, 4=Sub-Alphine. AEZs are elevation zones.

Figure 4.1. 12. The spatial distribution of exposure to climate variability among the agroecological zones (AEZs)

		Observed values across Jema Watershed		Indexed values among the AEZs of			
Profiles	Indicators	Maximum	Minimum	Moist-Cool	Cold	Moist-Cold	Sub-Alphine
Climate variability	Variability in onset time (being late) of rainy season in the last 15 years (in month).	1.50	0.50	0.500	0.500	0.750	0.750
	Variability in end date(earlier) of rainy season in the last 15 years (in month).	2.00	0.75	0.400	0.600	0.800	0.800
	Variability in duration of rainy season in the last 15 yea (in month).	3.50	1.00	0.100	0.400	0.800	0.800
	Standard deviation of the average ATRF (in mm)	189.88	109.43	0.569	0.440	0.297	0.297
	Standard deviation of the average daily max temp by month (in ^{0}C).	3.71	0.85	0.617	0.662	0.702	0.702
	Standard deviation of the average daily min Temp by month(in ^{0}C).	3.82	0.83	0.355	0.310	0.253	0.253
	Average value			0.424	0.485	0.600	0.600

Table 4.1. 5. The indexed values for indicators of exposure to climate variability to climate variability among the agroecological zones (AEZs)

Overall, in terms of exposure to climate variability, higher elevation areas that are situated towards eastern direction of the watershed were more vulnerable. It was manifested mainly in differences in the values of variability in onset time of rainy season, variability in end dateof rainy season and variability in duration of rainy season. The small scale (country level) study of MOEF (2014) identified the same parameters of climate variability indicated above as the major risks in the AEZs of north-western part of Ethiopia. Moreover, because of the 2015/16 ENSO event, drought was sever towards the eastern part of the country (WFP and FAO, 2016).

The variability could negatively affect the crop calendar and the whole farming schedule. The problem manifests itself not only in reduction of production, but also in increment of rural employment and price of food crops. Ultimately, the local people would face shortage of food and forced migration. All these adverse effects would be immediate and more severe in areas where the economy depends on rainfed and subsistence farming, and where the ecosystem is more degraded. A similar finding was noted in the research works of Degefa (2005); Devereux et al. (2003); and Mesfin (1984).

Summary of the Section

The focus of this study is to investigate the spatio-temporal variability of exposure to climate variability (the average: ATRF, ATRF, MTmax and MTmin) among the AEZs (Moist-Cool, Cold, Moist-Cold and Sub-Alphine) of the Jema watershed, north-western Ethiopia. The spatial pattern of RF is investigated and mapped employing spatial interpolation statistics. In the process of spatial pattern analysis, the most accurate and precise interpolation models were identified using cross-validation statistics in the ArcMap. The inter-annual variability of the average ATRF and MTmax and MTmin in the AEZs were analyzed employing SD. These analyses were made using the reconstructed meteorological values of 31 stations. The record Temp and RF covered the years from 1980 to 2010 and 1983 to 2010 respectively. Moreover, for spatial pattern analysis (interpolation) of ATRF, elevation data was employed as a covariable. The inter-annual variability of off-set and on-set of rainy season and duration of rainy season was investigated based on a historical (in the last 15 or 20 years) analysis. This qualitative data was generated through focus group discussion (FGD) made with elderly local farmers.

The result revealed that based on root mean square error statistics, Ordinary Cokriging (OCK) was identified as the most accurate model with a predictive power of 87.3%. As indicated from root mean square standardized statistics, the best precision value (0.72) was observed in the same model. Topography (elevation) contributed to maximize the performance of statistical estimations, degree of accuracy and precision of estimation; however, the association between the values of ATRF and elevation was not straightforward across the entire interpolated surface. Overall, the entire study watershed experienced RF from 1228 mm to 1640 mm. Its spatial distribution showed a declining pattern from west (downstream part) to east (upstream part) of the watershed. With respect to the duration of rainy season and the onset and off-set time of rainy season, the upstream part of the watershed faced more variability. On average , compared to the past 20 years, the duration of rainy season became shorter by 4 weeks in the downstream and 6 weeks in the upstream. On the other hand, the inter-annual variability (SD) of the average ATRF showed higher variability in the lower part of the watershed. The value of the variability ranged from 133mm-155mm. With regard to the inter-annual variability (SD) of maximum and minimum Temp, the values ranged from 2.61^0C to 2.86 ^{0}C and 1.59^0C to 1.89 ^{0}C respectively. The maximum Temp showed an increasing pattern from the lower to the higher elevation. The pattern for the minimum Temp was in the reverse direction. Overall, as the indexed value of all the climatic indicators showed, the AEZs (Sup-Alphine and Moist-Cold) situated in the higher elevation part of the watershed were exposed to more climate variability.

4.2 Spatial Pattern of Soil Texture

This section presents the result and discussion on spatial variability of soil texture. Specifically, it deals with the data exploration, performance assessment of interpolation models as well as raster surfaces and their statistical description. The section ends by discussing the findings of the study.

4.2.1 Data Exploration (Preliminary Analysis)

Data Validation

The measured values of the entire texture data set (i.e., proportion of sand, silt and clay) in the watershed were in the range of 11.4-43.4, 6.0-34.8 and 21.8 -77.8 %, respectively. The result of linear regression showed an inverse association between sand (%) and bulk density; and yet it was not statistically significant. The same test revealed that like that of sand (%) and different from silt (%), bulk density showed a significant inverse relationship with elevation (Table 4.2.1). Accordingly, the data set was considered valid for making further scientific analysis. Cresswell, et al. (2002) and FAO (2007); and Tranter et al. (2007) explained that sandy soils have higher bulk density. Bulk density tends to increase with compaction, and it is a dependable indication of the suitability for soil permeability and root growth.

The result of the correlation analysis made between soil texture and bulk density attested the quality of soil sample data set. Other researchers who conducted related studies in other sites including Cresswell, et al. (2002), Jahn, et al. (2006), and Tranter, et al. (2007) came up with similar result on the association between the two soil properties.

Dependency among Variables

Based on the result of the dependency test (Table 4.2.1), a statistical association was observed between soil texture (predicted variables) and terrain attributes (auxiliary variables). Terrain attributes (slope and ellevation) have a direct relationship with sand and an inverse relationship with clay. Thus, slope and elevation values were considered as covariables for enhancing the performance of stochastic geostatistical interpolation methods. In such circumstances, employing Cokriging was regarded as a more dependable model for surfacing soil texture than that of kriking and deterministic model.

	Elevation (m)	Slope (%)	Clay (%)	Silt (%)	Sand (%)
Elevation (meter)[c]	-	-	-.804**	.457**	.848**
	-	-	.000	.005	.000
Slope (%) [c]	-	-	-.521**	.350*	.501**
	-	-	.001	.036	.002
Clay (%) [pc]	-.804**	-.521**	1	-.789**	-.869**
	.000	.001		.000	.000
Silt (%) [pc]	.457**	.350*	-.789**	1	.383*
	.005	.036	.000		.021
Sand (%) [pc]	.848**	.501**	-.869**	.383*	1
	.000	.002	.000	.021	
Bulk Density (t/m^3) [V]	-.536	.083	-.367	-.119	.635

**: Correlation is significant at the 0.01 level (2-tailed);
*: Correlation is significant at the 0.05 level (2-tailed); Number of observations=36
c: covariable; pc: predicted variable;
v: validating variable

Table 4.2.1. Summary of tests of correlation between the predicted variables and covariables

Stationary (Spatial Dependence)

To evaluate the presence of spatial autocorrelation, it was essential to analyze the semivariogram/covariance cloud (with in a variable) and the cross covariance cloud (between two variables). The semivariogram analyses showed that the stable model was the best fit to all the primary data sets (sand, silt and clay) (Figure 4.2.1: A, B , & C). This model became the best fit to the empirical data with 5 lags having 5 km lag size. The analysis on the crosscovariance cloud (Figure 4.2.2: A, B, C ,D, E, & F), computed with the same lag size and lag number, indicated the presence of cross correlation between the primary and secondary variables (i.e., slope and elevation). As shown in the crosscovariance cloud figures, the clouds are concentrated along the central horizontal line.

(A) Sand (B) Clay

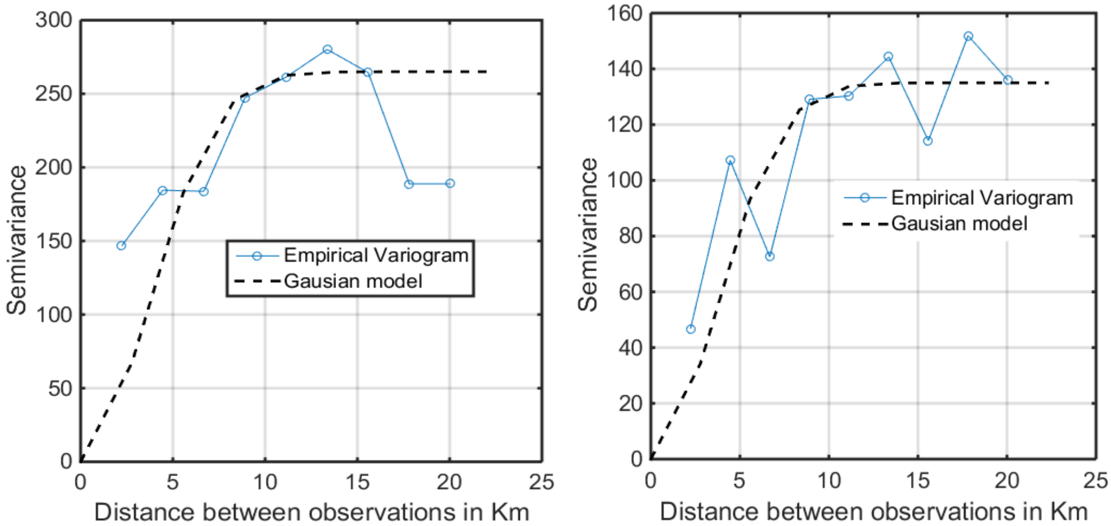
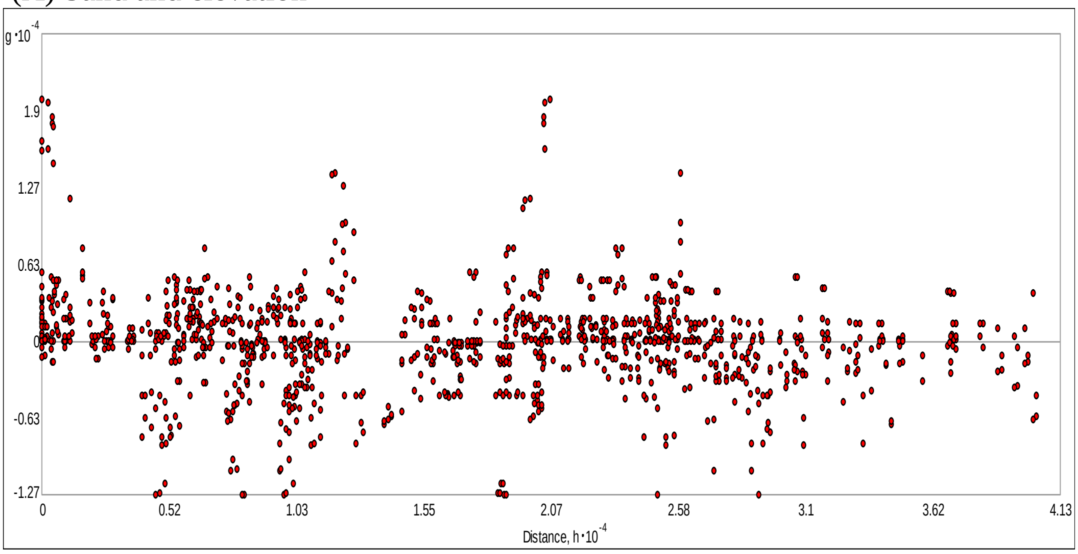
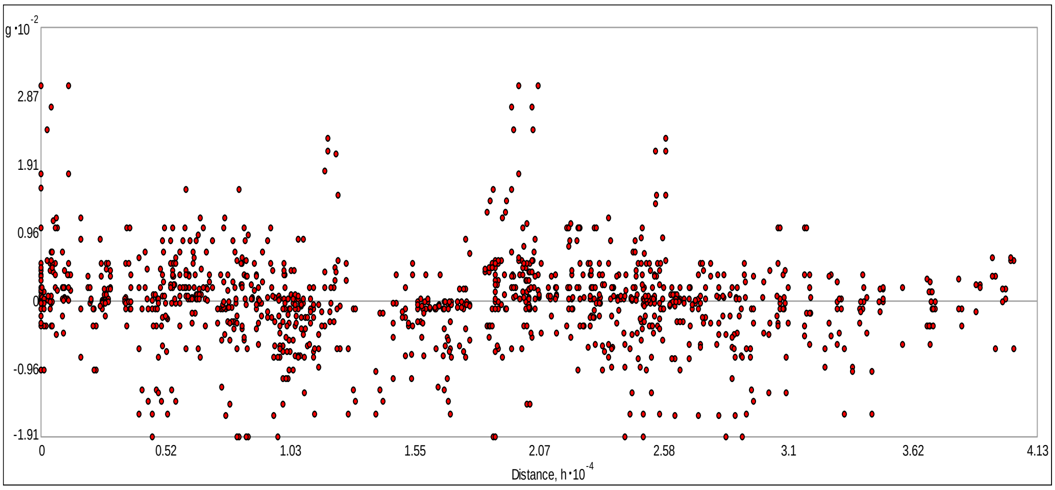


Figure 4.2. 1. (A & B). Semivariogram for the primary variables: sand % & clay %

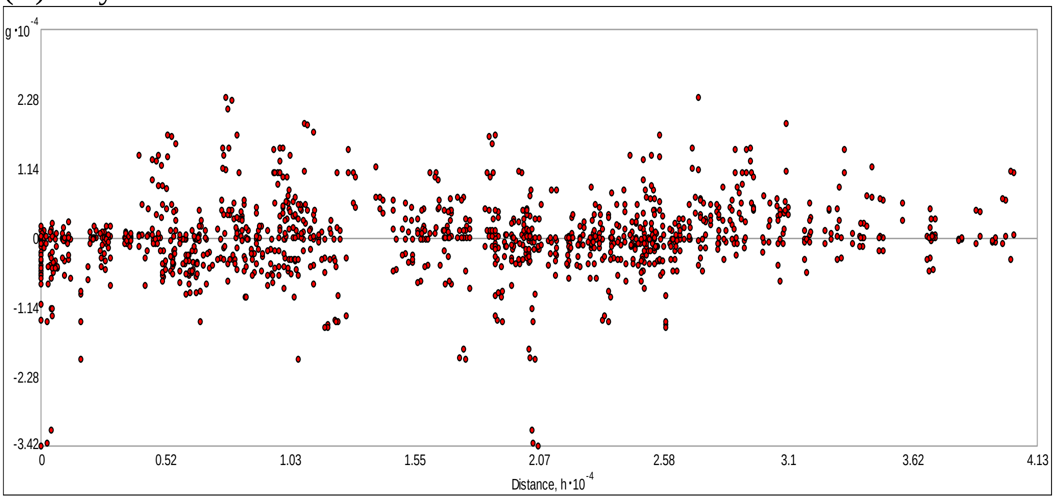
(A) Sand and elevation



(B) Sand and slope



(C) Clay and elevation



(D) Clay and slope

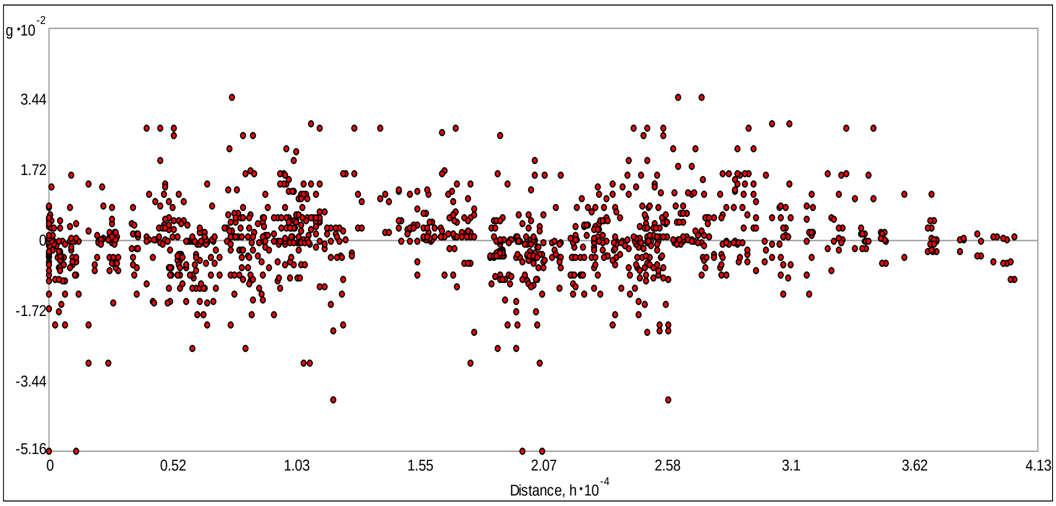
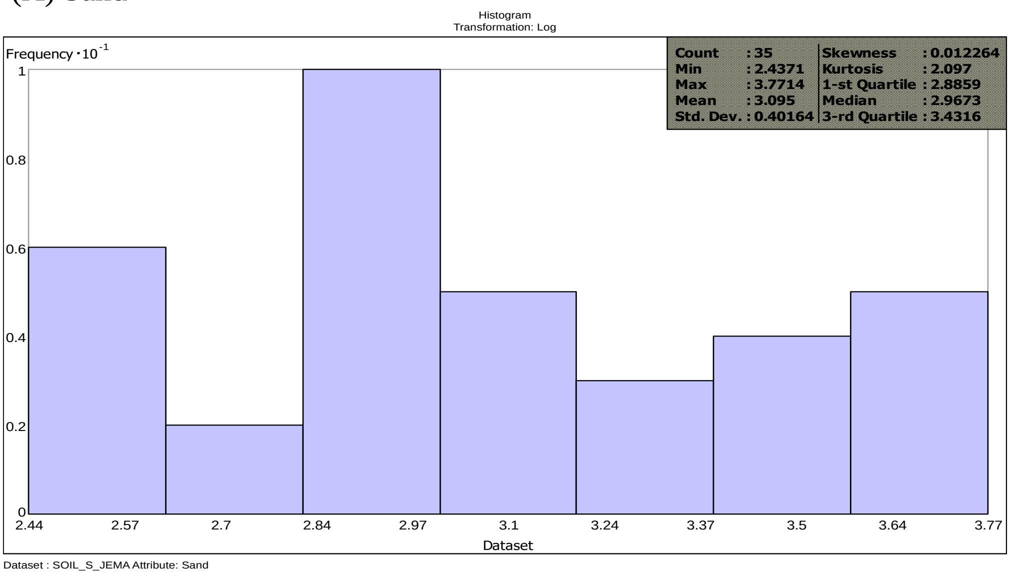


Figure 4.2. 2 (A, B, C & D). Crosscovariance cloud for primary variables (sand, silt and clay) with secondary variable (slope and elevation)

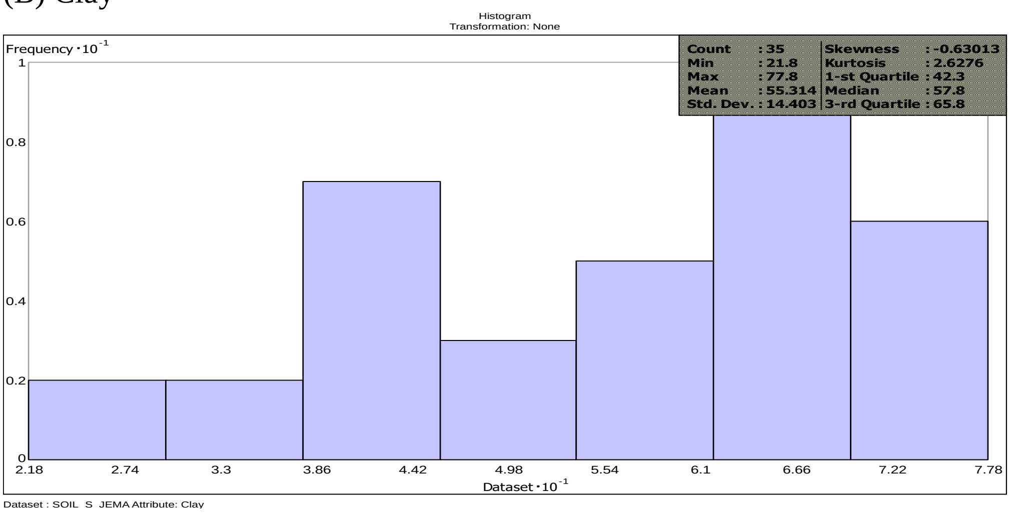
Data Normality

To keep the data distribution normal and to maximize the performance of the interpolation model, Log transformation was done on sand, altitude, and slope data sets. With regard to clay and silt data sets, the model showed better result without transformation. The entire results from the test are presented in the five graphs (Figure 4.2.3: A, B, C, D and E).

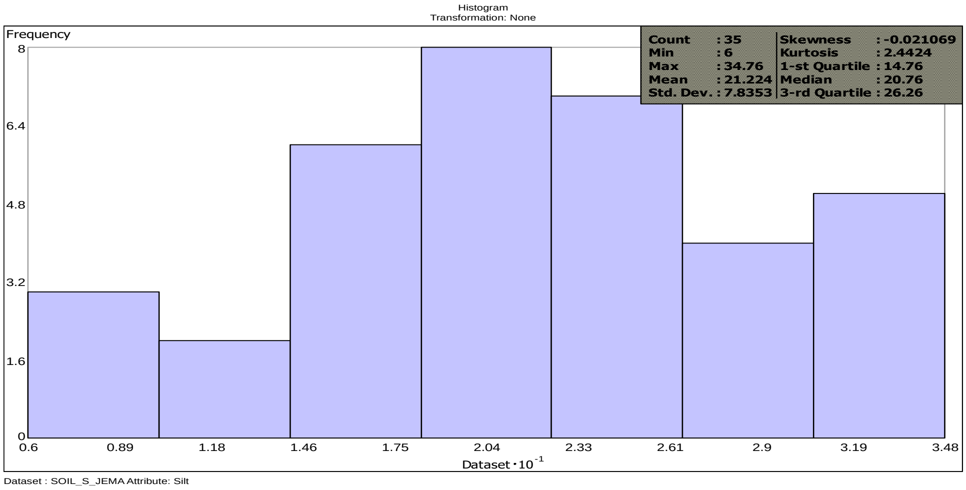
(A) Sand



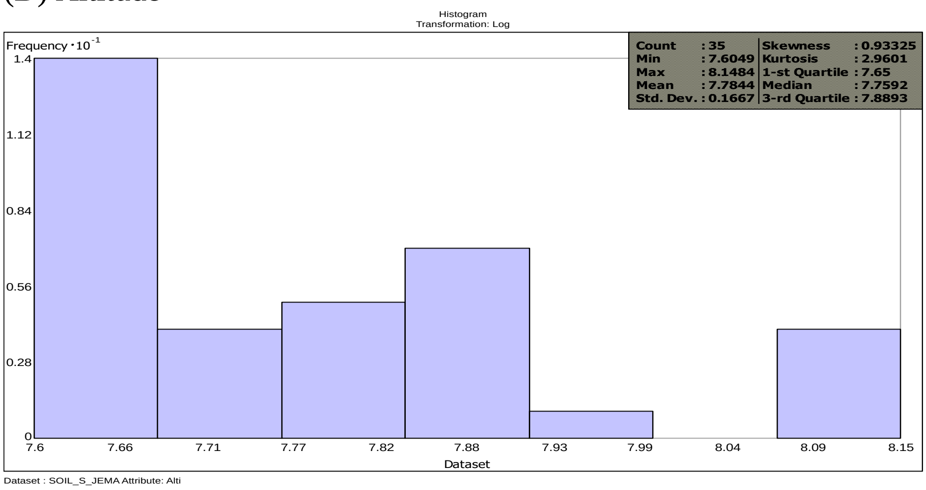
(B) Clay



(C) Silt



(D) Altitude



(E) Slope

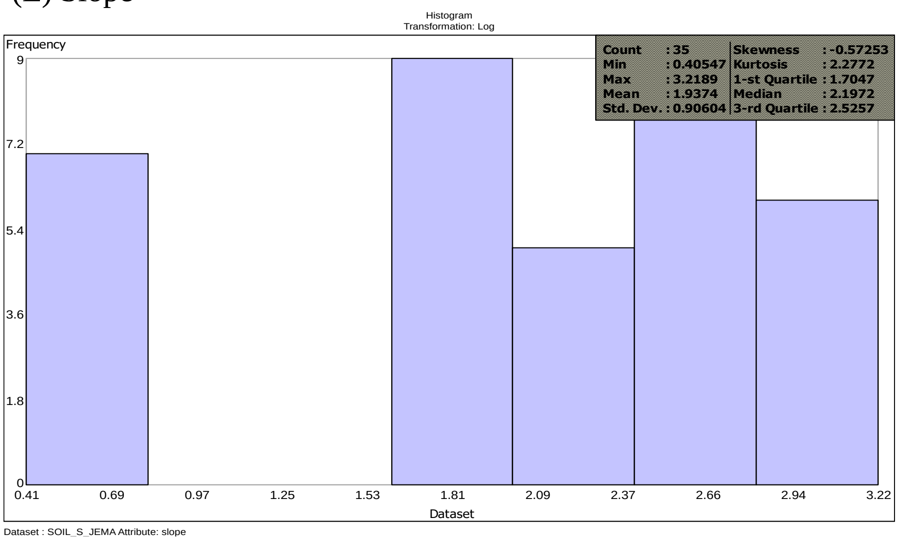


Figure 4.2. 3. (A, B, C, D & E). Normality test and data transformation for soil texture and terrain data sets

4.2.2 Evaluation of Model Performance

Geostatistical Functions

Given the differences in the nature of variability of elevation and slope across the watershed, one may attribute both global and local trends to account possible soil texture variability. The finding revealed that local trend interpolation analysis offers a more logical explanation of the soil texture variability. Accordingly, only the nearest 5 samples were considered to assign values for a given un-sampled location (a raster cell). Similarly, since the data set of texture showed smoothly varying property, stable semivariogram model (Figure 4.2.1) best fitted the model to the empirical semivariogram. Vázquez, et al. (2005) stated that due to the existence of transitional site in the variability of clay, sand and silt proportions across various classes of terrain), geostatistical models become more accurate with inexact (smoother) interpolation algorithm. It is important to note that in smoothly varying properties there may be local trends at a certain interval. In this regard, attending to the nature of the environmental variables to be interpolated and the geostatistical functions to be used is highly critical.

In the Jema watershed, elevation declines from south-east to north-west which indicates the presence of directional influence of terrain on soil texture. However, because of the existence of local trends created by the nature of slope variability, the geostatistical algorithm performed better owing to non-anisotropy factor (circular neighborhood search) geostatistical assumption. That is, for predicting soil texture values, the nearest 5 samples (minimum of 2 and maximum of 5) located in any directions were searched for analyzing estimations across the watershed. At the same time, the algorithm performed best considering the influence of distance without power function (at zero, non-weighting). All the interpolator functions that showed better performance in SCK were also powerful in other geostatistical models. In the overall analysis, the interactive effect of geostatistical function was found to be more powerful than individual effects. Thus, when applying geo-statistics in a complex agroecosystem setting, it is essential to take into account the interactive effect of multifaceted attributes and short term variations.

Model Optimality (Accuracy) Analysis

Overall, except GPI, all models revealed similar RMSE values (Table 4.2.2), and performed at a very low level of accuracy error. Relatively, Cokriging methods perform better than deterministic methods. Considering the value of RMSE, SCK proved to be the most optimal/accurate (its value was close to the measured value) model for interpolating soil texture (Table 4.2.2 and Figure 4.2.4). Moreover, the overall estimated value in the cokriging model showed the least deviation from the measured value. With regard to the result of MSE, the modeled value was underestimated by -0.07 for sand, and overestimated by 0.00 for clay and by 0.02 for silt. As per the result of RMSE, the model predicted the value of soil texture particles at various accuracy levels: 86.5 % for sand, 85.5 % for clay, and 77% for silt.

Model Uncertainty (Precision) Analysis

Unlike that of optimality test, the precision test resulted in considerable difference among models. The SCK, as it did in the optimality test, performed best in the error variability test. A look into the value of RMSSE and ASE (Table 4.2.2), the most consistent value in prediction variability was generated by the same cokriging model.

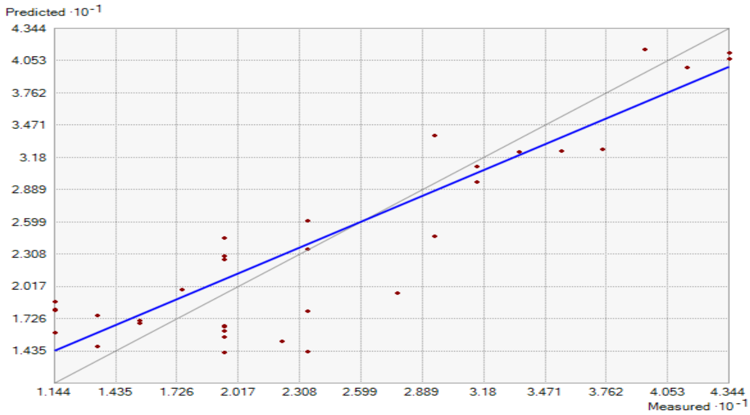
That is, in SCK, all prediction errors were found the most consistent. Therefore, SCK was considered as the most appropriate model to interpolate soil texture to the entire Jema watershed.

		Spatial interpolation model							
Error type	Texture class	OCK	SCK	UCK	DCK	OK	SK	UK	DK
	Sand	0.48	-0.27	0.29	0.39	0.18	-0.28	0.18	-0.68
	Clay	0.65	0.16	0.39	0.20	-0.05	-0.10	0.02	-0.23
M	Silt	0.19	0.21	0.16	0.60	-0.00	0.06	0.07	0.12
	sand	4.79	4.32	4.73	5.56	5.70	5.64	5.70	5.38
	clay	8.63	8.09	8.37	9.46	10.63	10.68	10.66	11.24
RMSE	silt	6.70	6.59	6.46	6.62	7.18	7.13	7.13	7.22
	sand	0.05	-0.07	0.96	-0.02	0.01	-0.07	0.46	-0.17
	clay	0.04	0.00	1.63	0.02	-0.00	-0.02	0.00	-0.02
MSE	silt	-0.03	0.02	0.33	0.04	-0.00	0.01	0.01	0.01
	sand	0.77	1.01	14.29	1.21	0.85	1.10	15.35	1.45
	clay	0.73	0.79	32.61	0.88	0.90	0.90	0.910	0.89
RMSSE	silt	0.83	0.80	14.33	0.82	0.10	1.00	0.11	0.10
	sand	7.94	6.12	0.33	5.53	8.59	7.05	0.40	6.53
	clay	14.17	10.05	0.26	10.82	12.36	11.81	12.05	12.63
ASE	silt	9.36	8.86	0.45	8.87	7.26	7.10	7.26	7.26

*: Not Applicable; M: Mean; RMSE: Root-Mean-Square Error; MSE: Mean Standardized Error; RMSSE: Root-Mean-Square Standardized Error; ASE: Mean Standard Error; OCK: Ordinary Cokriging; SCK: Simple Cokriging; UCK: Universal Cokriging; DCK: Disjunctive Cokriging; IDW: Inverse Distance Weighted; GPI: Global Polynomial; LPI: Local Polynomial; RBF: Radial Basis Functions.

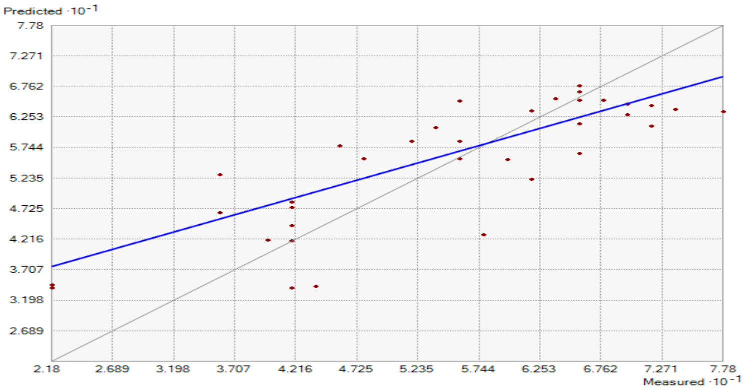
Table 4.2.2. The performance of geostatistical models for interpolating soil texture

(A) Sand



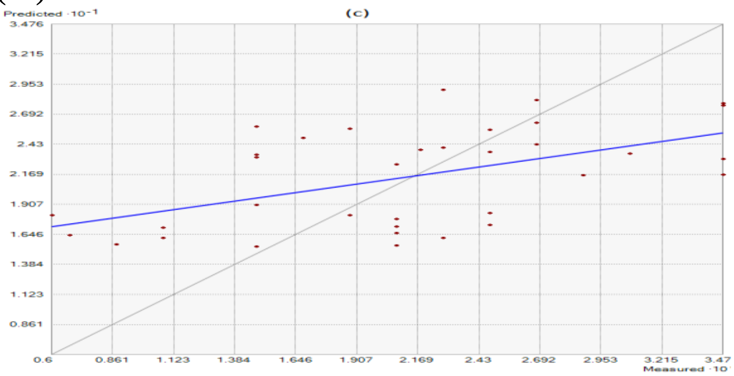
Regression function for sand (%) =0.800517629782014 * x + 5.20782247611666

(B) Clay



Regression function for clay (%) =0.565667439982037 * x + 25.2779775876941

(C) Silt



Regression function for silt (%) =0.283847466048741 * x + 15.4217541963383

Figure 4.2.4. (A, B & C). The predicted value versus the measured value for soil texture particles: sand %, clay % and silt %

Overall, the entire process of texture class interpolation analysis showed the superiority of an interactive effect of geostatistical assumptions. With respect to the interpolation models, Cokriging was found to be the most useful. Taking into account the geostatistical context appropriate to this study, slope and elevation are taken as determinant variables for the spatial distribution of soil texture class.

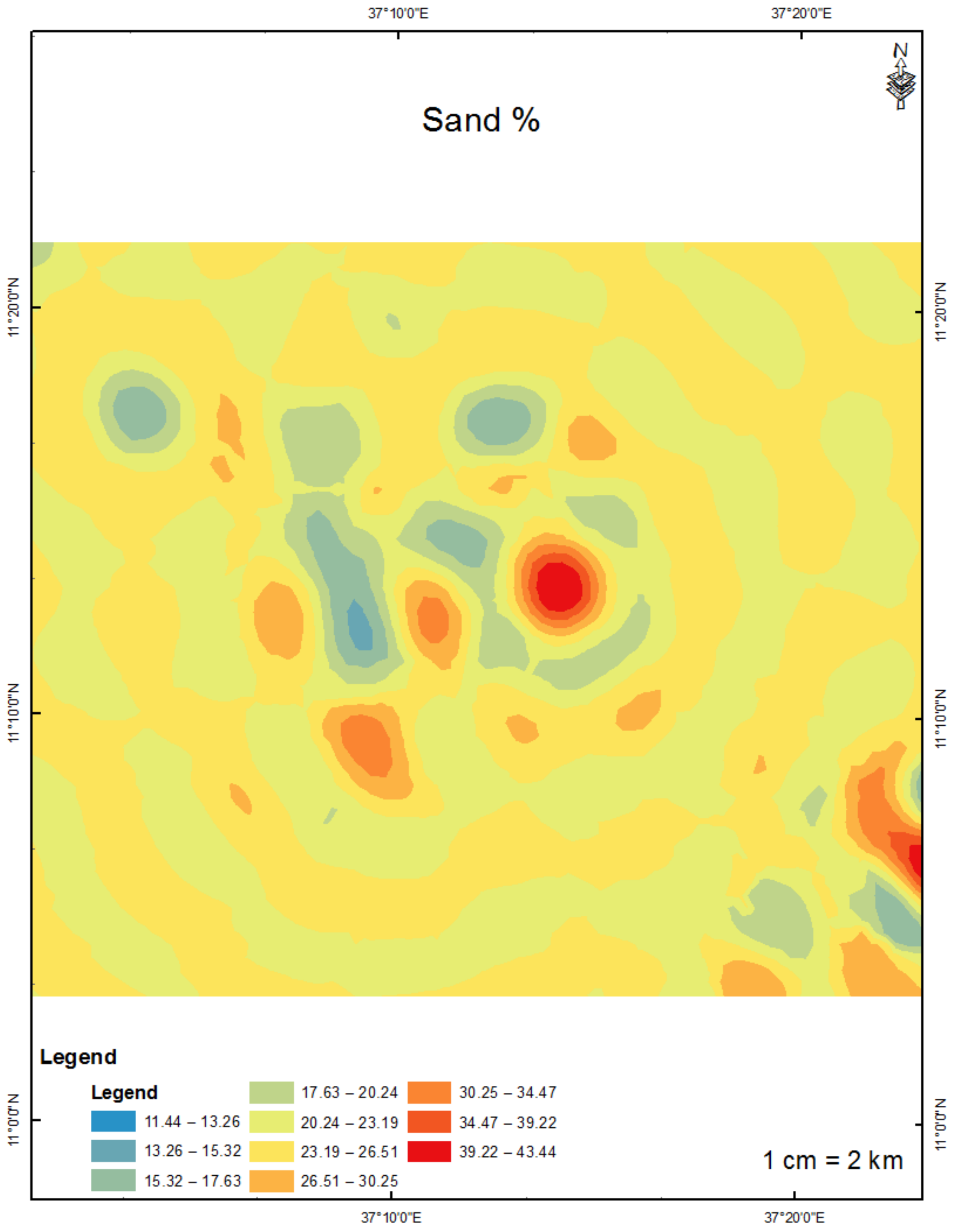
4.2.3. Statistical Description of Interpolated Surfaces

The interpolated surfaces of sand, clay, and silt are presented in Figure 4.2.5. Furthermore, the surface of aggregated soil texture class and its geographical area coverage are presented in Figure 4.2.6 and in Table 4.2.3 respectively.

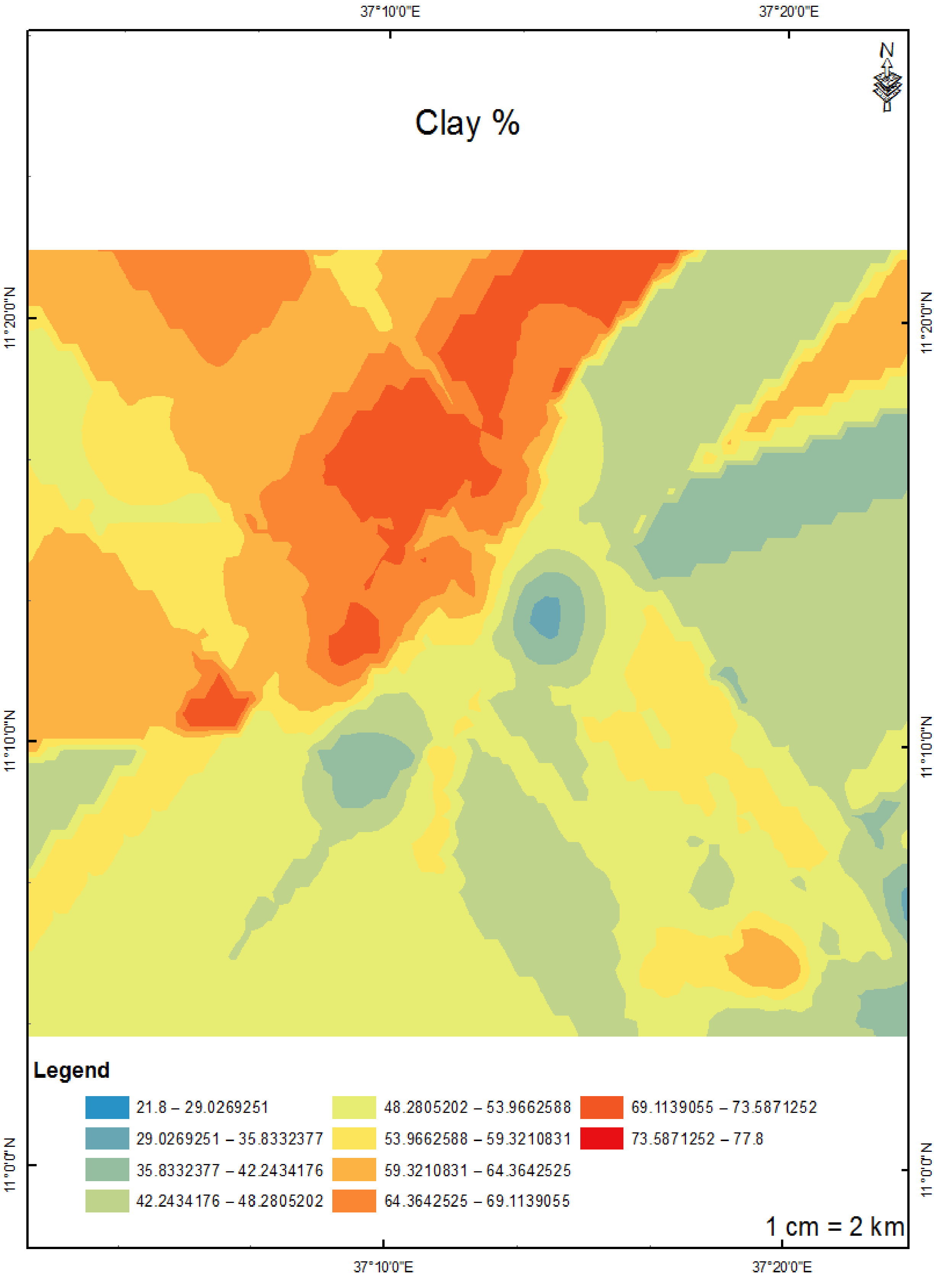
Texture class	Area coverage (Km^2)	Area coverage (%)
Heavy clay	184.940	38.217
Clay	254.402	52.572
Clay loam	44.571	9.211
Total	483.915	100

Table 4.2. 3. Area coverage of soil texture classes for the Jema watershed

(A)



(B)



37°10'0"E
37°20'0"E
Clay %
N
11°20'0"N
11°10'0"N
11°0'0"N
Legend
21.8 – 29.0269251
29.0269251 – 35.8332377
35.8332377 – 42.2434176
42.2434176 – 48.2805202
48.2805202 – 53.9662588
53.9662588 – 59.3210831
59.3210831 – 64.3642525
64.3642525 – 69.1139055
69.1139055 – 73.5871252
73.5871252 – 77.8
1 cm = 2 km

(C)

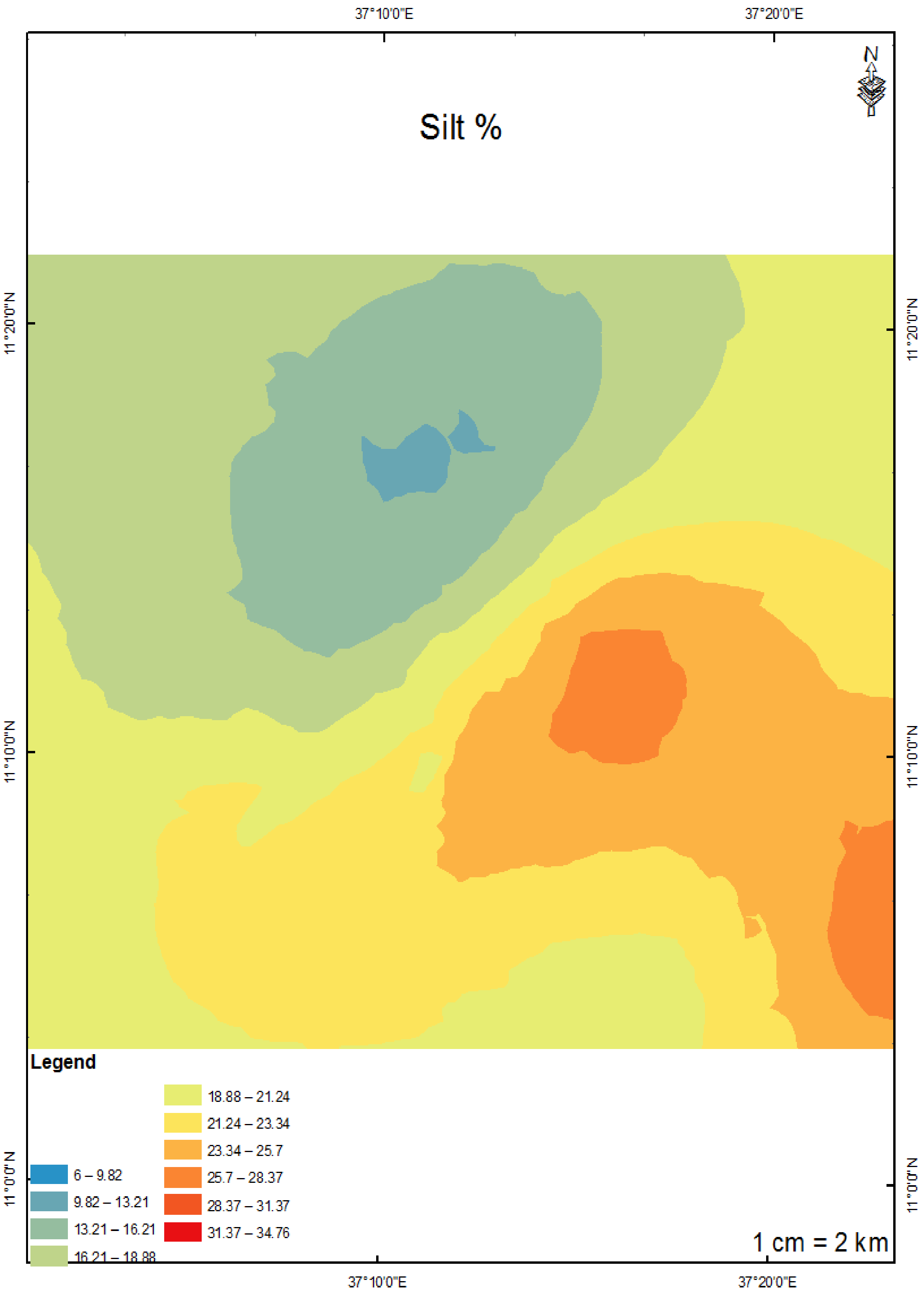


Figure 4.2. 5 (A, B & C). Predicted output surface for soil texture particles (sand, clay and silt)

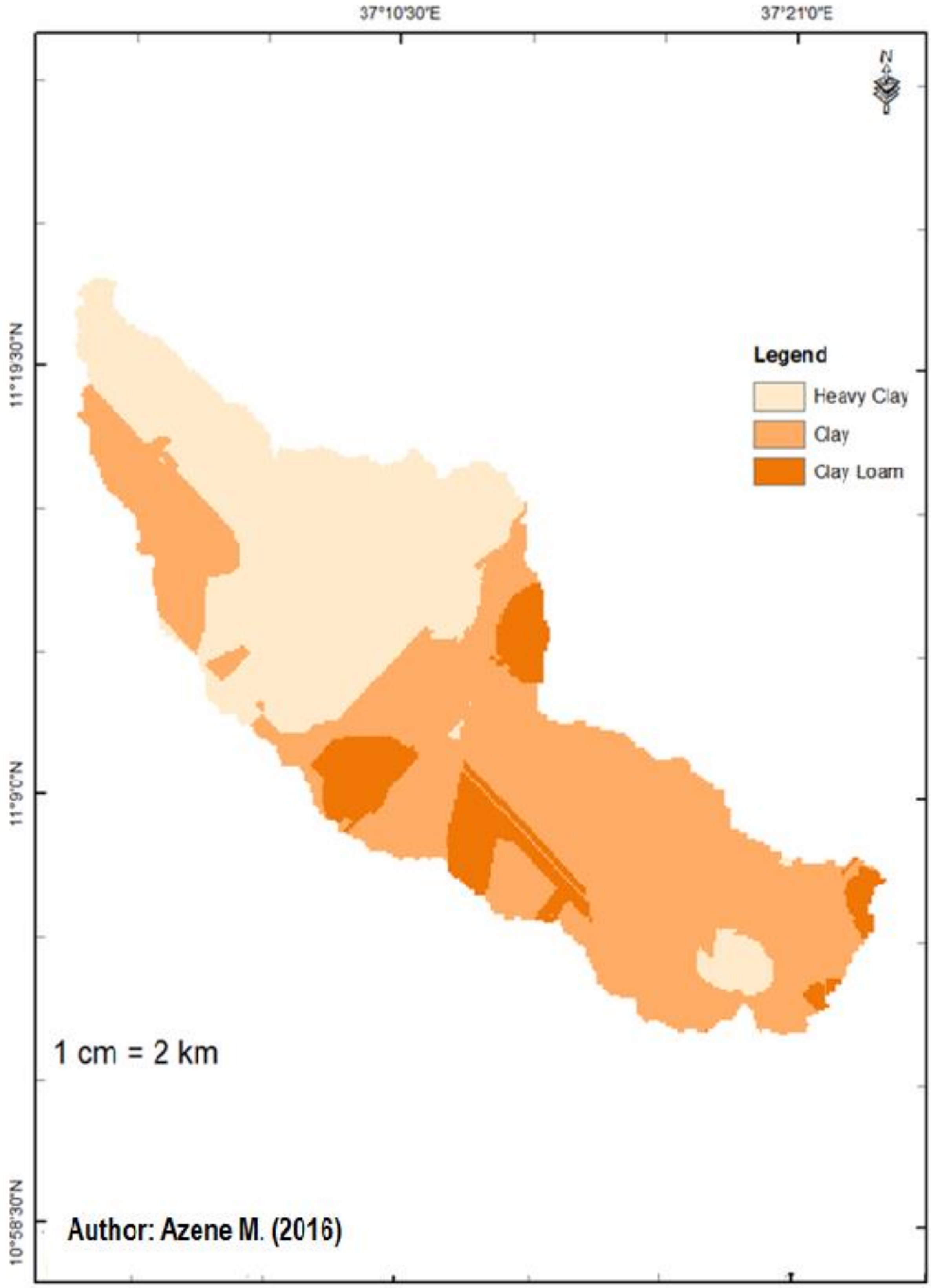


Figure 4.2. 6. Predicted output surface for the combined soil particles (texture class)

For the spatial variability of relatively permanent environmental variables like soil texture class, directional influence could be caused by a geological structure, terrain, and runoff (Setegn et al., 2009; Webster, 2008). It is also important to note that a geographical scale of analysis and the degree of complexity of terrain may also affect the result. Accordingly, in the watershed understudy, heavy clay, clay, and clay loam were found as the major texture classes in the lower, middle and higher elevations respectively. This indicates the complexity of terrain in the study site. The distribution of soil texture class in the entire watershed showed a global trend; however, there were breaks from the global trend in a few micro-watersheds. In general, the result implied the existence of spatial autocorrelation between soil texture and terrain attributes. Thus, the result was consistent with the theory of catenary[42] soil development (Webster, 2008).

In contrast, in a smaller scale study by Berhanu, et al. (2013), it was found that the texture class of the watershed was condensed only to clay texture class. The different findings might be attributed to the differences in the geographical scale of analysis and the complexity of the terrain in the north-western part of the country.

Looking at the nature of soil texture, the water holding capacity of the soil can be regarded as low in the entire watershed and especially severe in the downstream. It signified the prevalence of erosion in the upstream and siltation in the downstream.

[42] In catenary soil development approach, there is a sequence of soils down a slope, created by the balance of processes such as precipitation, infiltration, and runoff Catenary soil development is mainly true for a relatively permanent soil properties like texture (Bockheim, et al., 2005).

Together with pore space, bulk density and organic matter, soil texture influences available water holding capacity, nutrient retention capacity, soil erodeability, and soil and water conservation planning (Birhanu, 2013; FAO, 2007). Because of the existence of larger sized pores in sandy soil, there is higher infiltration, and less available water holding capacity to plants. In clayey soil, its fine pore size results in less infiltration, and high water holding capacity, and less available water holding capacity to plants. In both cases, water stress can be observed. Unlike sandy soils, clayey soil does not drain more water. As a result, it permits longer growing periods to plants (FAO, 2006). However, the LGP may be affected by other factors like evapo-transpiration. With regard to LGP, in the Jema watershed, the effect of evapo-transpiration may be more dominant than that of soil texture. It is noted from FGD and field observation that LGP was longer in the upstream where cloud cover is observed over a longer period of a year (4.5.1).

In the Amhara Regional State, where the study watershed is situated, 4.25% of the land falls under the slope class of 32%, whereas 45% is under 0 to 8% (BOFED, 1993/94)., All slope classes identified in the region are also observed in the Jema watershed. In terms of elevation zone proportion, 9.85% of the land in West Gojam falls under *Kolla* AEZ (BOFED, 1993/94). This elevation zone is not found in the Jema watershed. And yet, the overall proportion of Moist-Cool (70.5%), Cold (19.3% and Sub-Alphine (0.37%) AEZs that are found in the Amhara Regional State are also found in the Jema watershed with a comparable proportion. The coverage of Moist-Cool Cold and Sub-Alphine AEZs in the Jema watershed are (59.5%), (38%), and (0.9%) respectively. This indicates the presence of more complex topography in the Jema watershed. Assuming that elevation and slope classes are determinants of soil texture distribution; the finding implies the existence of similar soil texture spatial pattern in the Jema watershed and the larger Amhara Regional State. Yet, this statement can be reasonable if and only if the overall regional state has the same geological foundation.

Summary of the Section

This section deals with soil texture characterization in the AEZs of Jema watershed through employing geostatistical statistics. Bulk density (t/m^3) was analyzed for validating the value of soil texture data set. A total of 36 composite samples were collected using auger and the samples were subject to laboratory analysis, while a total of 90 samples were collected using core sampler for bulk density analysis. Samples for soil texture analysis were collected at the depth of 0 to 60 cm; whereas bulk density was examined from undisturbed samples which were dried at 105^0C to a constant Temp for 24 hours in advance. The texture samples were dried in the oven and sieved through 2 mm sieve. The samples were then collected using stratified random sampling technique. For determining the texture class, USDA soil texture triangle was referred. The values of coordinates and terrain attributes (elevation and slope) for each sample point were collected using DEM 30m r, GPS and Google earth. In the process of spatial interpolation, soil texture was a predictand (dependent variable), whereas elevation and slope were predictor variable (covariables). The result showed inverse correlation (-0.74) between soil texture (sand %) and bulk density (t/m^3). Among the eight interpolation models tested, based on its degree of robustness, universal cokriging (SCK) was found as the best model to interpolate soil texture classes. Based on the value of Root-Mean-Square Error (RMSE), its accuracy or predictive power was 86% (to sand), 77% (to silt), and 85% (to clay). As a result, heavy-clay (38.22 %), clay (52.57 %) and clay-loam (9.21 %) were identified as the major soil textural classes in the watershed. Overall, the texture was found to be more clayey towards the downstream.

4.3 Spatial Variability of Land Use-Land Cover

As part of comparing the degree of variability in agroecosystem sensitivity to climate variability, this section presents results and discussion of LULC types. It focuses on elaborating the proportion of LULC types in the AEZs of the study watershed and the indexed values of LULC types together with land capability classes and the other indicators. This section also explains the result of accuracy assessment made on the image analysis. Finally, it discusses the possible causes and implications of the different LULC types.

The result revealed that, in the entire study site, the proportion of grazing land, crop land, bush land, bare land, settlement land, forest land and water body were 42.09 %, 35.90 %, 8.95 %, 8.27 %, 2.58 %, 2.05 %, and 0.17 % respectively (Figure 4.3.1 and Table 4.3.1). Most of the area was used for and/or covered with grazing land and crop land. There were differences in the proportion of LULC types among the AEZs. And yet, there was no a linear spatial pattern in the distribution of each LULC type. At the AEZ level, the proportion of bare land (16.00 %) and open grazing land (8.28 %) were larger in *Moist Cold* and *Sub-Alphine* zones. On the other hand, the proportion of forestland was relatively larger in *Moist Cold* and *Cold* zones, whereas the percentage of bush land was larger in *Sub-Alphine* and *Cold* zones.

LULC Types	Area coverage and its proportion in the AEZs							
	Moist Cool Highland		Cold		Moist Cold		Sub-Alphine	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Bare land	1915.61	6.67	1357.99	9.14	687.38	16.00	38.03	8.28
Bush land	2307.80	8.04	1659.96	11.17	292.32	6.81	59.00	12.85
Cultivated land	12230.10	42.61	3768.01	25.35	1266.35	29.48	91.22	19.87
Forested land	367.83	1.28	473.00	3.18	139.39	3.25	6.39	1.39
Grazing land	11071.44	38.57	7270.90	48.93	1737.34	40.45	249.01	54.25
Settlement land	758.12	2.64	305.82	2.06	169.18	3.94	14.67	3.20
Water body	50.69	0.18	25.58	0.17	3.40	0.08	0.68	0.15
Total	28701.59	100	14861.25	100	4295.34	100	458.98	100

Table 4.3. 1. Area coverage (and its proportion) of the classified LULC types among the AEZs of Jema watershed

The statistical result presented above was observed in a situation where user's accuracy (column's value in %) and producer's accuracy (row's value in %) were not equal to different LULC classes. The overall statistical error report of the classification is shown in Table 4.3.2. The highlighted frequency values represent the main diagonal of the matrix that contain the cases where the class labels depicted in the image classification and ground data set match, whereas the off-diagonal elements containing those cases where indicate a mismatch in the labels. Thus, with regard to overall accuracy, 85.48 % of the classification was found to be accurate. With respect to reliability (Kappa Coefficient), the classification was 82.4% better than would have occurred strictly by chance. Thus, taking into account the recommendation of Monserud (1990), the output of the classification was accurate and reliable at a very good level.

		True class								
		1	2	3	4	5	6	7	Total	User's accuracy (%)
Predicted class	1	17	0	3	0	0	2	0	22	77.27
	2	0	14	0	1	1	0	0	16	87.50
	3	2	0	23	0	0	0	1	26	88.46
	4	0	1	0	19	0	0	0	20	95.00
	5	1	0	0	0	12	0	0	13	92.31
	6	0	0	0	0	0	11	2	13	84.62
	7	0	0	0	1	0	3	10	14	71.43
	Total	20	15	26	21	13	16	13	OAA=85.48 (%)	
	Producer's accuracy(%)	85.00	93.33	88.46	90.48	92.31	68.75	76.92		

OAA: Over All Accuracy; 1:Bare land, 2:Bush land, 3:Cultivated land, 4:Forested & Plantation area, 5: Grazing land, 6: Residential land, 7:Water body

Table 4.3. 2. Error matrix (accuracy assessment report) made for the classified LULC analysis

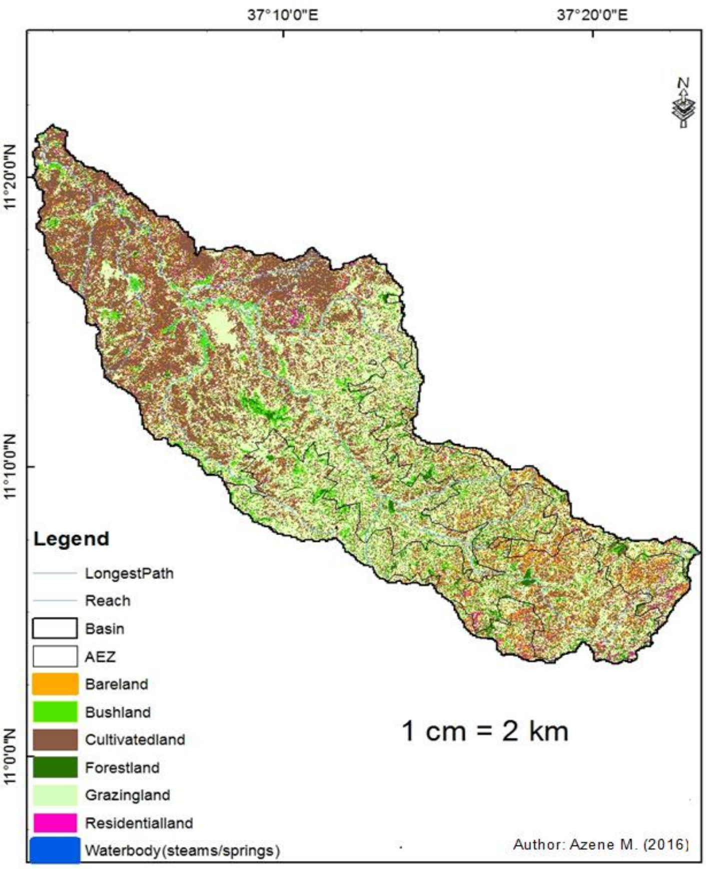


Figure 4.3. 1. The distribution of classified LULC types in the AEZs of the Jema watershed

In developing countries, poverty is considered as a major driving force for land degradation including deforestation (Forsyth and Leach, 1999). However, in this study, the distribution of forest land and bush land covers in the four AEZs showed insignificant inverse relationship with the aggregate wealth distribution in the area (Table 4.3.4). The correlation value was -0.2 for wealth and forestland indexes, and -0.5 for wealth and bush land indexes. A possible explanation is that the poor farming communities with a relatively better wealth status developed the means and capacity to clear the forest and bush covers into farmland and grazing land. It is important to note that Ethiopian farmers have been categorized as living under subsistence economy (MOFED, 2002) which needs to be upgraded to achieve a sustainable land management (MOARD, 2010).

AEZ	Wealth index	Forest land cover/use	Bush land cover/use
Moist-Cool	0.186	1.28%	8.04%
Cold	0.144	3.18%	11.17%
Moist-Cold	0.157	3.25%	6.81%
Sub-Alphine	0.135	1.39%	12.85%

Table 4.3. 3. Index for wealth versus forest and bush land covers/uses among the AEZs of the study site.

Large population size has also been taken as a cause for deforestation in developing countries (Bewket, 2003; Hurni and Pimentel, 1993; Malthus, 1798). On the other hand, Boserup (1965) and Woldetsadik (2003) found out that population size was not inversely related to the size of forest cover. As the country's demographic data was compiled only in accordance with the administrative structures: sub-districts, districts and provinces (CSA, 2008), it was difficult to make a statistical comparative analysis on the association between population size and forest cover proportion in the AEZs of the study watershed. In the future, this concern might receive attention from development and research experts.

Given the distribution of LULC types, specifically the proportion of bare land and bush land (Table 4.3.1), the agroecosystem of the entire watershed could be regarded as sensitive to climate variability, variability. In addition, since most of the forest cover was dominated by eucalyptus tree that have sparse canopy (Local Farmers-FGD, 2014), the existing limited forest would have little potential to reduce run-off (FAO, 2007). Accordingly, the area is most likely to face severe soil loss predominantly in parts of the watershed where the slope is stepper. As proved by Setegn et al. (2011) and Gebremicael et al. (2012), these places would be subjected to high surface run off and low water retention. As a result, gully formation and siltation would increase in the upstream and downstream elevations respectively. Ultimately, there would be constraints in soil fertility and moisture availability for crop cultivation.

In general, previous studies have identified farmlands as the most sensitive LULC type (Bewket, 2003). This study, however, considered farmland size only as an indicator of measuring HDs's wealth status. Taking into account the relative area coverage of bare land, the ecosystem of Moist Cold could be considered as the most sensitive AEZ. Moreover, when considering bush land area coverage, the ecosystem of *Sub-Alphine* was the least sensitive AEZ. And, in terms of forest land size, the ecosystem of *Moist Cool Highland* and *Sub-Alphine* AEZs are more sensitive than that of the other AEZs. In terms of the overall LULC, *Sub-Alphine* AEZ is the most sensitive zone. The forestland cover proportion (2.05 %) of the Jema watershed was a little bit larger than the average forest cover of the Amhara National Regional State (0.5%). It implies the presence of comparable degree of problem in forest cover shrinking and soil loss in the study watershed and the larger region. In terms of cropland cover/use, the proportion was less in the Jema watershed than that of the Amhara National Regional State.

Summary of the Section

As part of agroecosystem sensitivity to climate variability analysis, this section dealt with the estimation of the size of various LULC types among the AEZs of the study watershed. The agroecosystem sensitivity was analyzed using LandSat8 30m r. This imagery was accessed from USGS archive in January 2014. A total of 380 sample polygons were collected for the seven major LULC types identified across the watershed. The proportion of sample LULC type (grazing land, crop land, bush land, bare land, settlement land, forest land and water body) was estimated and collected with the help of Google earth imagery and GPS. Nearly two third of the total sample data set was assigned for calibration (classifying the imagery), whereas the remaining data was used for validating the classified imagery. The image was classified using supervised method of classification in the ArcMap. Maximum likelihood classifier statistical tool was employed for analysis. The accuracy of the image classification was evaluated by computing confusion matrix and its Kappa Coefficient. According to the result of the analysis, in the entire watershed, the highest and least proportion of LULC was observed in grazing land (42.09 %) and in water body (0.17 %). At the level of AEZ, the proportion of bare land (16.00 %) and open grazing land (8.28 %) were huge in the higher elevation, that is, Moist Cold and *Sub-Alphine* AEZs. On the other hand, the proportion of forestland was relatively larger in *Moist Cold* and *Cold* AEZs, whereas the percentage of bush land was larger in *Sub-Alphine* and Cold zones. With respect to performance assessment, the overall accuracy of the classification was 85.48 %, whereas its reliability was 82.4 % which is better than it would have occurred strictly by chance. Hence, the output was accurate and reliable at a very good level. Overall, there were differences in the proportion of all LULC types among the AEZs of the study watershed though a linear spatial trend was not observed in the distribution of the LULC types.

4.4 Spatial Pattern of Land Capability Class

This section presents analysis and discussion of land capability class of Jema watershed. It is analyses taking into account soil, slope, elevation and rainfall data. The result is accompanied with spatial maps and their interpretations.

Based on the result of LCC analysis that was conducted considering slope (%), elevation (m), soil texture (%) and average ATRF (mm), four (II, III, IV and V) USDA LCC were identified (Figure 4.4.1). Their area coverage was described to the entire Jema watershed (Table 4.4.1) and among the AEZs of the watershed (Table 4.4.2). Most of the land in the watershed was characterized by LCC-III, while LCC-V was found only in the two AEZs (*Sub-Alphine* and *Moist Cold*) situated in the higher elevation.

LCC	Area (ha)	%
II	13778.71	28.56
III	22067.29	45.74
IV	10690.41	22.16
V	1707.72	3.54
Total	48244.12	100.00

Table 4.4. 1. Area coverage of different LCCs in the entire study site

	Area coverage (%) in each of the AEZ			
LCC	Moist-Cold	Cold	Moist-Cool	Sub-Alphine
II	47.92	0.00	0.56	1.75
III	43.75	59.07	16.00	12.82
IV	8.34	40.93	46.66	52.62
V	0.00	0.00	36.78	32.82

Table 4.4. 2. Area coverage of LCCs among the AEZs of the study site

Finally, for comparing the degree of agroecosystem sensitivity to climate variability among the AEZs, the results of LULC and LCC spatial distribution together with the other agroecosystem sensitivity indicators were standardized and summarized as shown in Table 4.4.3. This indexed value of fell in the range of 0.378 to 0.460. The distribution of agroecosystem sensitivity among the AEZs was found to be explained by a spatial linear trend where the value of R^2 was 0.82 (Figure 4.4.2). The highest value was observed in the *Sub-Alphine* AEZ. And yet, no statistical group mean difference was observed (Table 4.6.4).

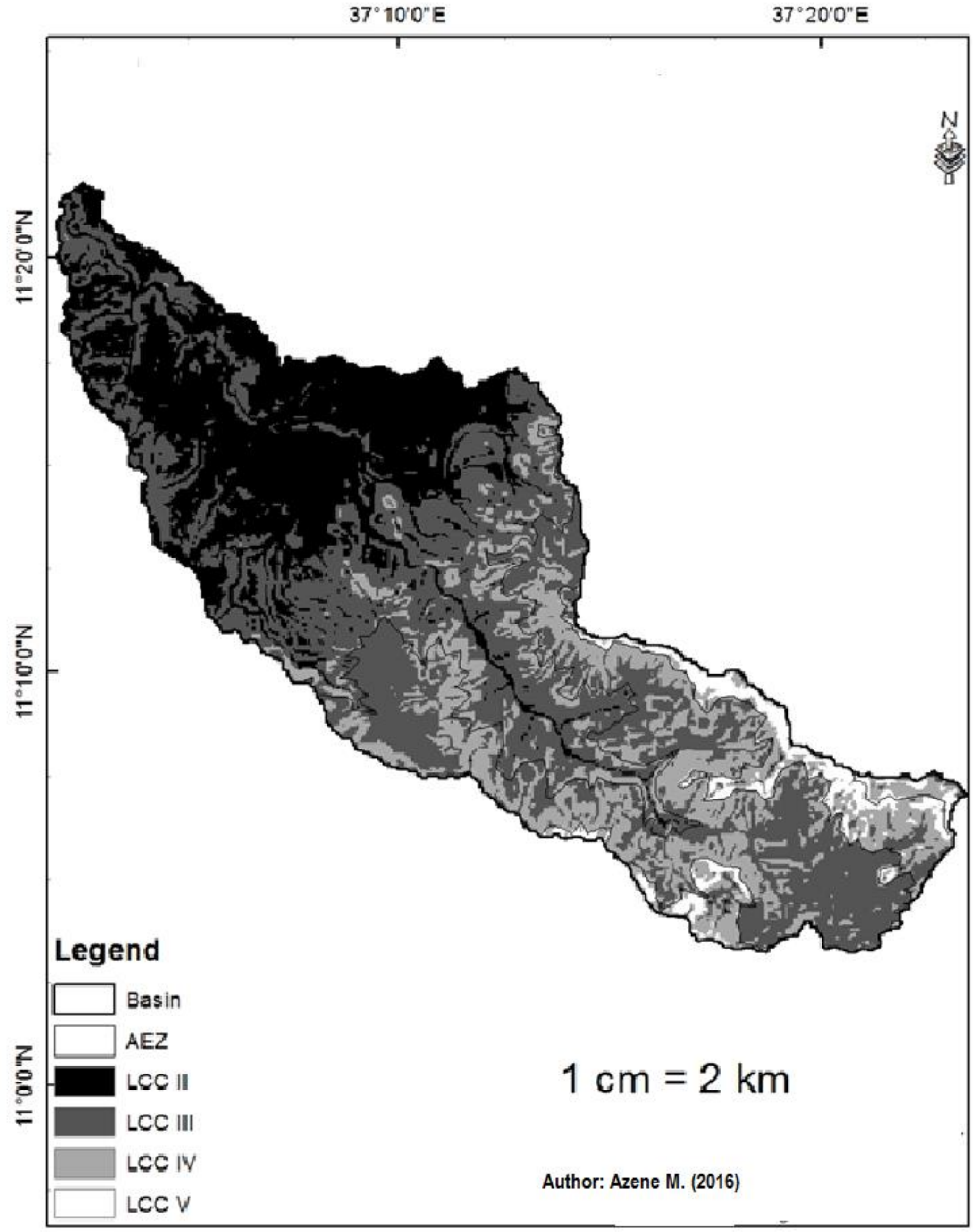
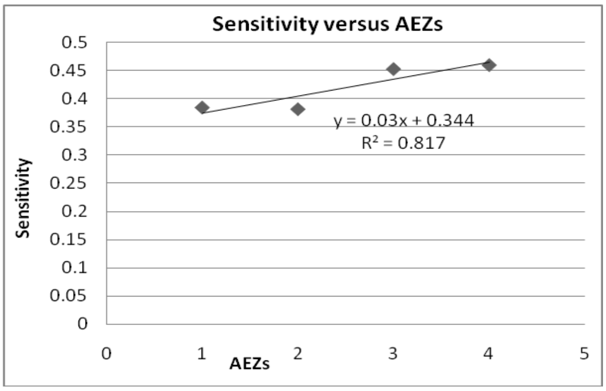


Figure 4.4.1. LCC distribution among the AEZs of the Jema watershed

Indicators of agroecosystem sensitivity to climate variability	Observed values		Standardized	AEZs		
	Maximum	Minimum	Moist-Cool	Cold	Moist-Cold	Sub-Alphine
Proportion of arable land-LCC II (in km^2).	100.00	0.00	0.025	1.000	0.691	0.417
Proportion of arable land-LCC III (in km^2).	100.00	0.00	0.032	0.024	0.082	0.100
Proportion of arable land-LCC IV (in km^2).	100.00	0.00	0.167	0.039	0.034	0.031
Proportion of arable land-LCC V (in km^2).	100.00	0.00	1.000	1.000	0.052	0.057
Proportion of bush land (in km^2).	100.00	0.00	0.926	0.082	0.936	0.886
Proportion of forest land (in km^2).	100.00	0.00	0.987	0.239	0.969	0.986
Proportion of water body, stream water (in km^2).	100.00	0.00	0.998	0.855	0.999	0.999
Accessibility (in minutes) of spring/stream water.	2.00	0.00	0.676	0.585	0.552	0.518
Average ATRF (in terms of rain water harvesting potential) (in mm).	1,640.00	1,228.00	0.001	0.001	0.001	0.001
Livestock diversity index.	7.00	1.00	0.194	0.196	0.243	0.251
Crop diversity index.	5.00	2.00	0.222	0.222	0.250	0.323
Proportion of bare land (in km^2).	100.00	0.00	0.001	0.001	0.002	0.001
Gully as a major environmental problem (in qualitative scale).	100.00	0.00	0.070	0.857	0.905	1.000
(Length of growing period (LGP) for major growing crops (in week).	7.00	3.00	0.000	0.250	0.625	0.875
Average value			0.378	0.382	0.453	0.460

The analysis was done at a confidence interval of 95%, and with a missing data of 3%.

Table 4.4. 3. The indexed values of agroecosystem sensitivity to climate variability among the AEZs of Jema watershed



1=Moist-Cool, 2=Cold, 3=Moist-Cold, 4=Sub-Alphine. It is given for the x-axis values.

Figure 4.4. 2. The spatial distribution of agroecosystem sensitivity to climate variability in the agroecological zones (AEZs) of the study site

The result of analysis indicated that there were differences in the distribution of LCC among the AEZs of the study watershed. Accordingly, it was discovered that all land segments were not endowed with the same agricultural potential due to the variation in slope, elevation and soil. Most (~96.5 %) of the land that was used for crop cultivation in the Jema watershed could be categorized under arable land; whereas, the remaining portion was non-arable. Though very intensive cultivation cannot be exercised in the entire watershed, limited cultivation with proper land management can be exercised all over the watershed except in LCC-V (3.5 %) of the watershed. Much of the land with LCC-V was situated more in the higher elevation areas, *Sub-Alphine* and *Moist Cold* AEZs. In terms of agriculture potential, more limitation of land was found to be in the upstream part of the watershed. The implications discussed above are in line with USDA LCC guideline (Davidson, 1992). Accordingly, with regard to LCC, the agroecosystem sensitivity to climate variability declined as we go from the upstream to the downstream part of the watershed. Similarly, in the study conducted in Guila-Abena watershed, northern Ethiopia (Ahmed et al., 2010) 4 major land capability classes (II, III, IV and V) were identified. In the study of Tegenie (2003) conducted in

Gido watershed, northern Ethiopia, the capability of the land falls into more than 4 classes ranged from I to IV.

Overlaying LCC V (Figure 4.4.1) with cultivated land use layer (Figure 4.3.1), it was possible to found out that no land in *Moist Cool* and *Cold* AEZs, ~405 ha of land in *Moist Cold* AEZ, and ~32 ha of land in *Sub-Alphine* AEZs were cultivated on potentially non-arable land. Hence, ~765 HDs[43] in the *Moist Cold* and ~60 HDs in the *Sub-Alphine* are expected to make a strategical shift in their economic activities from cultivation to non-cultivation practices. It was found out that the land which had to be cultivated moderately (i.e., LCC III and IV) have been ploughed with near to zero fallow ratio, and high labor per unit of land (i.e., 5 family members per 1.3 ha of land)[44].

In terms of land use, this study proved that a good part of the land segments were not utilized in accordance with their comparative advantages. This could happen possibility due to scarcity of farmland induced by high annual total population growth rate (3% per year at regional level) (CSA, 2008), expansion of gully (Figure 4.4.2), the prevailing high soil lose at the rate of 300^{+} tons/ha/year at national level (Hurni, 1998), and low level expansion of technology, farmers encroached to non-arable and steep slope land segments for cultivation and settlement purposes (Figure 4.6.5). The existing low level land productivity and economic poverty (MOARD, 2010) accompanied with the weak institutional setup of land use and land administration (MOEF, 2011) has pushed farmers to encroach into marginal lands. Studies conducted in the Ethiopian highlands indicated

[43] The average agricultural land holding size in the Jema watershed was 1.3 ha per HD.

[44] In practical terms, the internal working age limit does not work in Ethiopia. In the Jema watershed, it was observed that children with an age of 12 to 18 commonly take part in various agricultural activities.

that the way some farmers utilize and conserve their land and environment was not in line with the capability of the land (MoARD, 2010; Zeleke and Hurni, 2001).

The result of this study implies that unless the ongoing poverty reduction programs (including safety nets) could enhance non-cultivation and alternative livelihood strategies, 3.5% (437ha) of the land that is being used for crop cultivation would be more exposed for extremely natural resources and environmental values sever loss of endanger. Since this endangered land situated in the upstream, its effect will be multiple and can directly go to the downstream in various forms. For example, it could minimize the volume of surface stream flow and aggravate the problem of siltation. As a result, the efficiency of the farming system will become lower and lower with time all over the watershed.

Date: 2015
Figure 4.4. 2. Gully expansion in the Moist Cool AEZ of the Jema watershed

As compared to the national estimated value (~66 %), as per the observation of Land Use Planning Team of MOARD (MOARD, 2000), more proportion (~96.5 % %) of land in the Jema watershed could be categorized under potentially arable land. Likewise, as stated by MOARD (2000), 80 % of the agricultural activity was located in the highlands (located at > 1500m asl) of the country. And yet, most (~46%) of the arable land in the study site was covered by LCC III which potentially cannot be cultivated intensively. Moreover, LCC I was not found in any of the AEZ of the watershed.

With regard to livestock and crop diversity, the watershed was found to be rich in farming a diversified crop and livestock types. The reason could be the presence of diversified AEZs that ranges from Moist-Cool to Sub-Alphine. It was found out that farmers who were living the Jema watershed have a culture to cultivate all local livestock types except camel. Similar to the national and regional state level statistical report (CSA, and USDA, 2013), the local cattle, sheep, goat, horse, mule, poultry and beehives domestication were observed in the Jema watershed (Table 4.4.3). Likewise, the top five national major local grain crops (i.e., barely, maize, sorghum, teff and wheat) were also observed in the study watershed (Table 4.4.3). As indicated in this table, the spatial distribution (proportion) of both crop and livestock type was different among the AEZs of the watershed.

Summary of the section

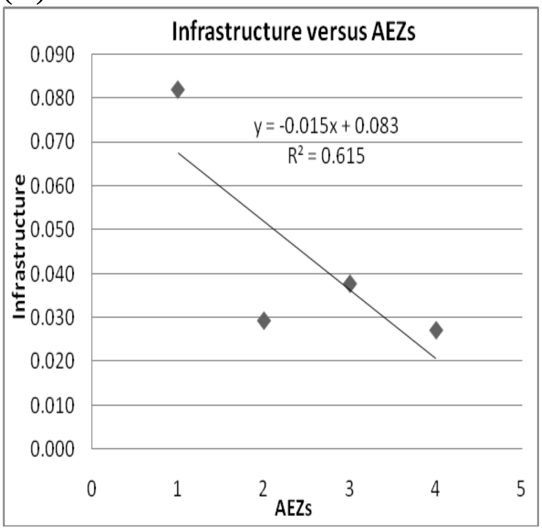
This section presents the results and discussion on the spatial variability of LCC among the AEZs of Jema watershed. LCC was analyzed taking in to account limitations of soil texture, slope, elevation and average ATRF. For all indicators, the same data sets employed in the previous section (spatial analysis of soil texture analysis) were used and the analysis was done using Map-Algebra function in the ArcMap. The degree of land limitation and its appropriate LCC was assigned in accordance with USDA LCC guideline. The result showed that the watershed consisted of both arable (LCC II, III and

IV) and non-arable land (LCC V). The arable land covered 96.5 % of the total size of the watershed. In general, it was observed that the degree of land limitation increased as one goes from the downstream to the upstream. Not only in terms of LCC, but also in the overall agroecosystem sensitivity, the aggregated value was found to be higher towards the upstream.

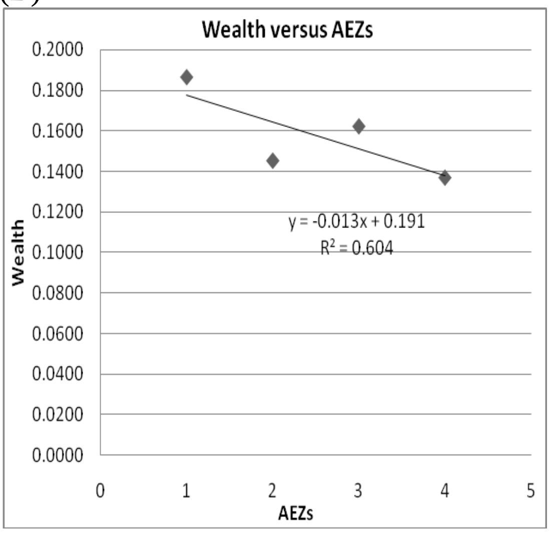
4.5 Spatial Variability of Adaptive Capacity to Climate Variability

The result indicated that the standard value of adaptive capacity to climate variability fell in the range of 0.235 to 0.277 (Annex 4.5.1). Spatial variation was detected in the aggregated standard value of adaptive capacity and its profiles among the AEZs (Figure 4.5.1: E, A, B, C &D). However, the aggregated spatial distribution of profiles of adaptive capacity were not found to be explained by a spatial linear trend (Figure 4.5.1: A, B, C, D & E); its R^2 value was 0.36. Furthermore, based on the test of One-Way-ANOVA, the spatial variability was not found to be statistically significant (Table 4.5.2).

(A)

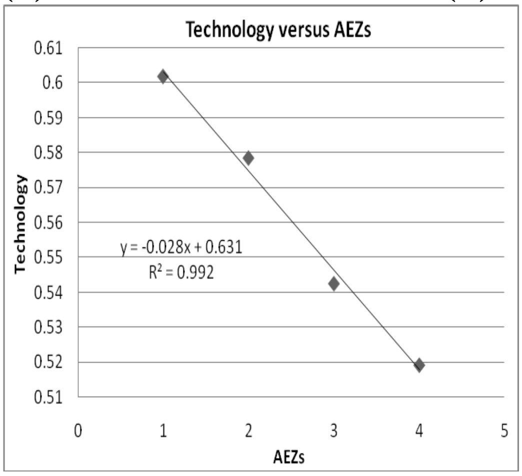


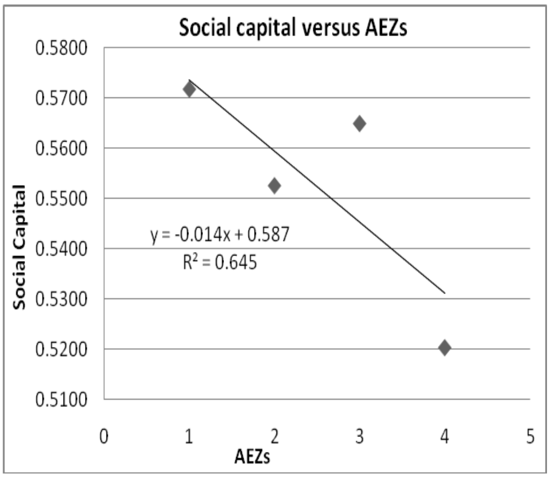
(B)



1=Moist-Cool, 2=Cold, 3=Moist-Cold, 4=Sub-Alphine. It is given for the x-axis values.

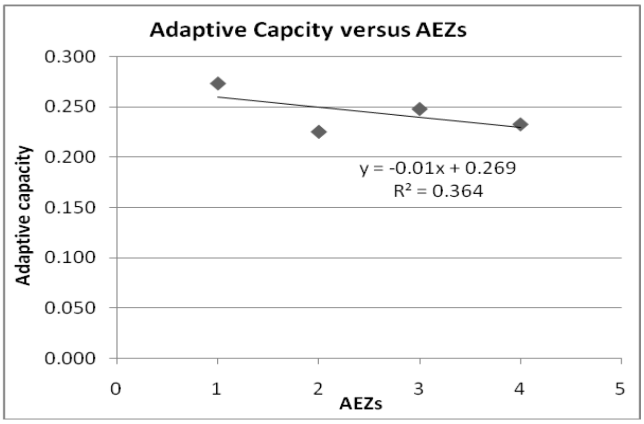
(C) (D)





1=Moist-Cool, 2=Cold, 3=Moist-Cold, 4=Sub-Alphine. It is given for the x-axis values.

(E)



1=Moist-Cool, 2=Cold, 3=Moist-Cold, 4=Sub-Alphine. It is given for the x-axis values.

Figure 4.5. 1. (A, B, C, D & E). A spatial linear trend for the indexed values of adaptive capacity and its profiles across the Agroecological Zones (AEZs)

Source of variation	Test result for adaptive capacity and its profiles			
	Social capital and Technology	Infrastructure	Wealth	Adaptive capacity
AEZs	P-value	P-value	P-value	P-value
	0.60	0.62	0.70	0.65

Df=3

Table 4.5.1.One-Way-ANOVA test result for the adaptive capacity to climate variability and its profiles among the AEZs of the Jema watershed

As indicated by MOEF (2014), the total investment in agriculture in Ethiopia was around $1bn of which around 40% came from within the MOARD. Between 2007-2013, 60% of the MOARD's budget was spent on activities relevant to resilience practices. However, the finding of this study showed that the adaptive capacity of communities all over the study watershed is still low.

Like that of exposure and sensitivity to climate variability discussed in the previous sections, variation was observed in the level of adaptive capacity to climate variability among the AEZs of the study watershed. The observed spatial variation in adaptive capacity among the AEZs of Jema was induced by cumulative differences in the four profiles: wealth status (farmland size; income from crop production, livestock rearing, off-farm and non-farm activities), technology adoption (improved seed, biogas and chemical fertilizer), access to infrastructure (gravel road, school, health center, telephone service, electricity and market), and the prevailed social capital (literacy, cooperation, proportion of working age population and regular number of working days in a month).

With respect to the overall adaptive capacity and its profiles (wealth, technology adoption, infrastructure and social capital), all the AEZs of the Jema watershed was found to be poor. In relative terms, the most upstream part was found to have the least level of adaptive capacity; however, this spatial variation was not explained by a spatial linear trend. In terms of technology adoption, a strong linear spatial pattern was there among the AEZs; whereas, wealth, social capital and infrastructure profiles did show a moderate linear spatial pattern among the AEZs. Yet, there was no a significant group means difference among the AEZs in adaptive capacity to climate variability and all of its profiles.

Relatively, among the measured indicators, the least standard value was recorded in access to gravel road to go to a regular market. This value was found as the major one to make Sub-Alphine AEZ at the bottom in terms of infrastructure. This could be associated with the presence of more complex terrain in the most upstream part of the watershed. Likewise, the least standard value recorded in *"income from Crops"*, *"experience in taking credit" ,"application of biogas technology"* were the major indicators that made more differences in the overall values of wealth, social capital and technology profiles respectively. The least income from crops was observed in the Sub-Alpine AEZ partly for the fact that the AEZ situation was the least suitable for producing more expensive local crops like *teff* (Eragrostis) and *nug* (Guizotia Abyssinica). The reverse was true for the Moist-Cool AEZs. The observed least size of cow, ox, bull and heifer in the Sub-Alphine AEZ was associated with the least application of biogas technology. The Cold AEZ was at the bottom in terms of adopting technology in general.

Similar to the findings noted above, Alamirew (2010), Deressa et al. (2009), Simane et al. (2014) proved that there existed spatial variation among AEZs in the profiles of adaptive capacity. However, the direction of spatial variability across the AEZs was not similar in those studies. In terms of wealth distribution, Alamirew (2010) found statistically significant variation among the AEZs. The inconsistency in the outputs of the studies could be attributed to the complexity of terrain and farming system in the country.

In terms of adaptive capacity, i.e., making the degree of exposure and agroecosystem sensitivity to climate variability constant, the Sub-Alphine AEZ would be the most vulnerable zone. Unless more scientific strategies are designed and implemented, AEZs (or communities) with less adaptive capacity would be engaged in activities that could cause further agroecosystem degradation. This would aggravate with encroachment to steep slope, to conserved forest land and bush lands both for cultivation and settlement. Further, it would force farmers to migrate to towns even in the farming season. This would be more likely in years of RF irregularities. This explanation is in line with the global observation of Environmental Kuznet's Curve (Todaro and Smith, 2012) which maintains that poverty (poor adaptive capacity) is both the cause and consequence of environmental degradation. A finding from a case study conducted in the northern part of Ethiopia (Alamirew, 2010) also supports this argument. In relation to this, though theoretically, the country's development policy-ADLI (MOFED, 2006) has incorporated a general statement that responds to this research findings.

In terms of farm land holding size per HD, compare to the national and regional state average values, farmers in the Jema watershed have less size of land (~1.3 ha) than that of the national and regional average values. That is, the average landholding size at national and regional state level was estimated to be 1.4 ha and 1.77 ha respectively (CSA and World Bank, 2013). This might happen because of the presence of higher population growth rate (3%)[45] and high population density (189.4 persons/km^2)[46], and less size (1.3 ha) of arable land per HD in study watershed.

With respect to adoption of any kind of alternative non-farm enterprises, compare to the national value (19.1%), less proportion of farmers (16.4%) was observed in the Amhara National Regional State. In the case of the Jema watershed, the proportion of farmers who engaged in non-farm and off-farm economic activities was even lower than the regional average, i.e., 10.7%. In relative terms, a larger proportion of HDs (18%) who live in the downstream was found to be in a position to adopt alternative off farm and non-farm activities. This might result in less adaptive capacity among the farmers who live in the regional state in general and the study site in particular. Consistent to the findings of this study, CSA and World Bank (2013) reported that lack of financial service, market and transport infrastructure were the top three major constraints in establishing non-farm enterprises.

The average household (family) size at national level and Amhara Regional State level were 5.1 and 4.6 respectively. The proportion of population with an age of 18-64 was 49% at national level, and 51.5 % at the Amhara National regional State level (CSA and World Bank, 2013). The average household size (~5) and the proportion of working age population (59.5%) of the Jema watershed were a little bit higher than the national and regional statistical reports. In relative terms, a larger proportion of working age population (65%) was observed in the upstream. The national literacy

[45] The average total population growth rate of West Gojam Administrative Zone, Amhara Regional State (CSA,2008).
[46] The average estimate of population density of West Gojam Administrative Zone, Amhara Regional State (BOFED,2012).

level (for reading and writing in any language) was 44.5%, whereas the literacy level in local language in the Jema watershed was 37%.

Summary of the Section

This section presented results and discussion on wealth status, status of social capital, access to infrastructure and adoption of technology to compare disparity in adaptive capacity to climate variability among the AEZs of the watershed. The analysis was made using data generated through employing structured questionnaire and FGD. LVI-IPCC was used as a statistical procedure to standardize values and figure out the existing differences. The aggregated value of adaptive capacity to climate variability and its profiles exhibited spatial differences. The standard value of adaptive capacity was 0.277, 0.225, 0.248 and 0.233 in Moist-Cool, Cold, Moist-Cold and Sub-Alphine AEZs respectively. There was no statistically significant group mean difference. Moreover, the difference was not found to be explained by a linear trend. And yet, in relative terms, the top most part of the watershed has the least adaptive capacity. AEZs identified to have lower adaptive capacity would require more attention in this regard.

4.6 Spatial variability of Livelihood Vulnerability to Climate Variability

As part of data quality assessment, the homogeneity of variance is tested using F-test, and the result is presented in Table 4.6.3. The test is made between a pair of the AEZs for the computed index values of all factors of livelihood vulnerability to climate variability. In all cases, P-values > 0.05, and F values > F Crit, i.e., homogeneity of variance is observed in the distribution of all livelihood vulnerability factors' data sets. Moreover, the normality of the data sets' distribution of the factors indicated above is tested using skewness. This is done for each of the AEZ separately. The result indicated that all the values of skewness were close to zero, i.e., ranges from 0.11 to 0.19 (Table 4.6.2). These values were observed with log transformation. Hence, the data sets satisfy an essential precondition to run inferential statistical analysis.

The digest of the computed level of LVI to climate variability and its factors (exposure to climate variability, agroecosystem sensitivity and adaptive capacity to climate variability) among the AEZs of Jema watershed is summarized and presented in Table 4.6.1. Table 4.6.5 presents the level of LVI together with their computed geographical area coverage and estimated total HD size among the AEZs of the watershed. This indexed value of overall livelihood vulnerability fell in the range of 0.057 to 0.130. This value declined from the lower to the higher elevation part of the watershed. The spatial linear trend value (R^2) for exposure, sensitivity, adaptive capacity and livelihood vulnerability are 0.82, 0.85, 0.36 and 0.88 respectively (Figure 4.6.1). Yet, the test of ANOVA (Table 4.6.4) shows that there is no significant group mean difference among the AEZs in livelihood vulnerability and its factors.

AEZ	Indexed value Exposure	Adaptive capacity	agroecosystem sensitivity	Vulnerability
Moist-Cold	0.408	0.277	0.384	0.052
Cold	0.432	0.246	0.381	0.064
Moist-Cool	0.525	0.248	0.453	0.126
Sub-Alphine	0.514	0.235	0.460	0.130

Table 4.6. 1. The indexed values for vulnerability to climate variability and its factors among the AEZs of the study site

	AEZS			
Factors of vulnerability	Moist-Cold	Cold	Moist-Cool	Sub-Alphine
Exposure	-0.12	-0.13	-0.11	-0.12
Agroecosystem Sensitivity	-0.16	-0.17	-0.15	-0.19
Adaptive capacity	0.19	0.18	0.16	0.18

The test was made after making log transformation.

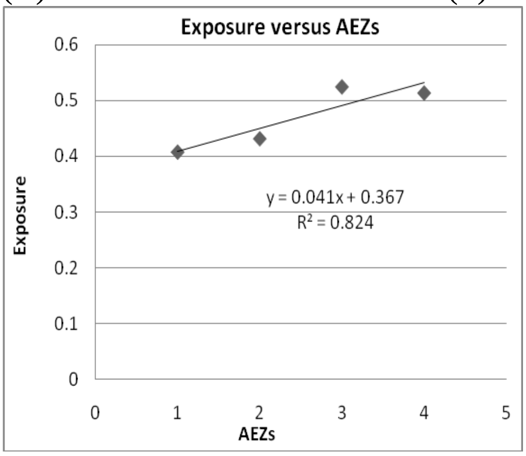
Table 4.6. 2. Normality of data distribution test made for data sets of factors of vulnerability to climate variability.

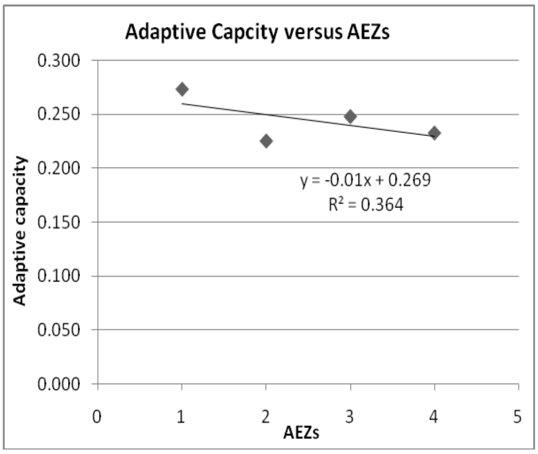
AEZs	AEZs Cold			Moist-Cold			Sub-Alphine		
	EX	AC	AS	EX	AC	AS	EX	AC	AS
Moist-Cool	0.22	0.37	0.32	0.25	0.39	0.43	0.25	0.2	0.43
Cold	*			0.08	0.47	0.39	0.23	0.16	0.40
Moist-Cold	*			*			0.50	0.46	0.41

EX: exposure to climate variability; AC: Adaptive capacity to climate variability; AS: Agroecosystem sensitivity to climate variability; in all cases, F values > F Critical; the test was made after making log transformation; *: not essential.

Table 4.6. 3. F-test (P-value) for the indexed values of factors of vulnerability to climate variability, for pairs of the AEZs

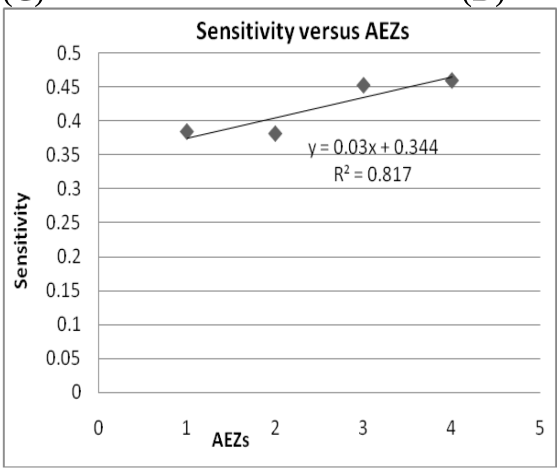
(D) (E)

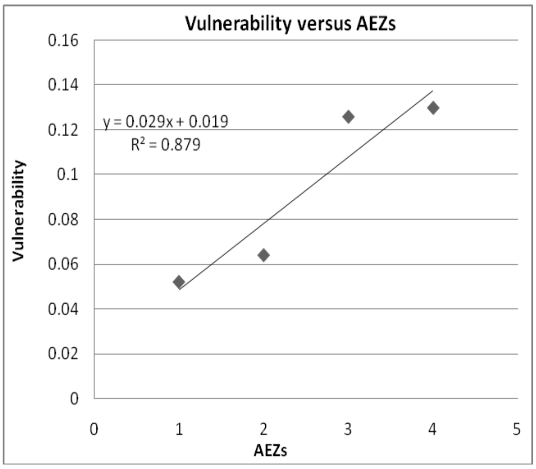




1=Moist-Cool, 2=Cold, 3=Moist-Cold, 4=Sub-Alphine. It is given for the x-axis values.

(C) (D)





1=Moist-Cool, 2=Cold, 3=Moist-Cold, 4=Sub-Alphine. It is given for the x-axis values.

Figure 4.6.1. (A, B, C & D). A spatial linear trend (distribution) for the indexed values of livelihood vulnerability to climate variability and its factors across the Agroecological Zones (AEZs) of the Jema watershed

	Test result for factors of vulnerability among the AEZs			
Source of variation	Exposure to climate variability	Adaptive capacity to climate variability	Agroecosystem sensitivity	Agroecosystem sensitivity and exposure to climate variability
AEZs	P-value	P-value	P-value	P-value
	0.59	0.88	0.92	0.52

Df=3

Table 4.6. 4. ANOVA test result for factors of vulnerability to climate variability among the AEZs

	AEZs				Jema watershed
	Moist-Cool	Cold	Moist-Cold	Sub-Alphine	
IPCC-LVI	0.052	0.064	0.126	0.130	*
Geographical area (ha)	28690	14863	4253	436	48,244
Geographical area (%)	59.47	30.81	8.82	0.904	100
Total HD size	10845	5618	1608	165	18, 236
Total population size	54225	28092	8039	825	91,181

*non-essential cell value

Table 4.6.5. The IPCC-LVI among the AEZs of the Jema watershed

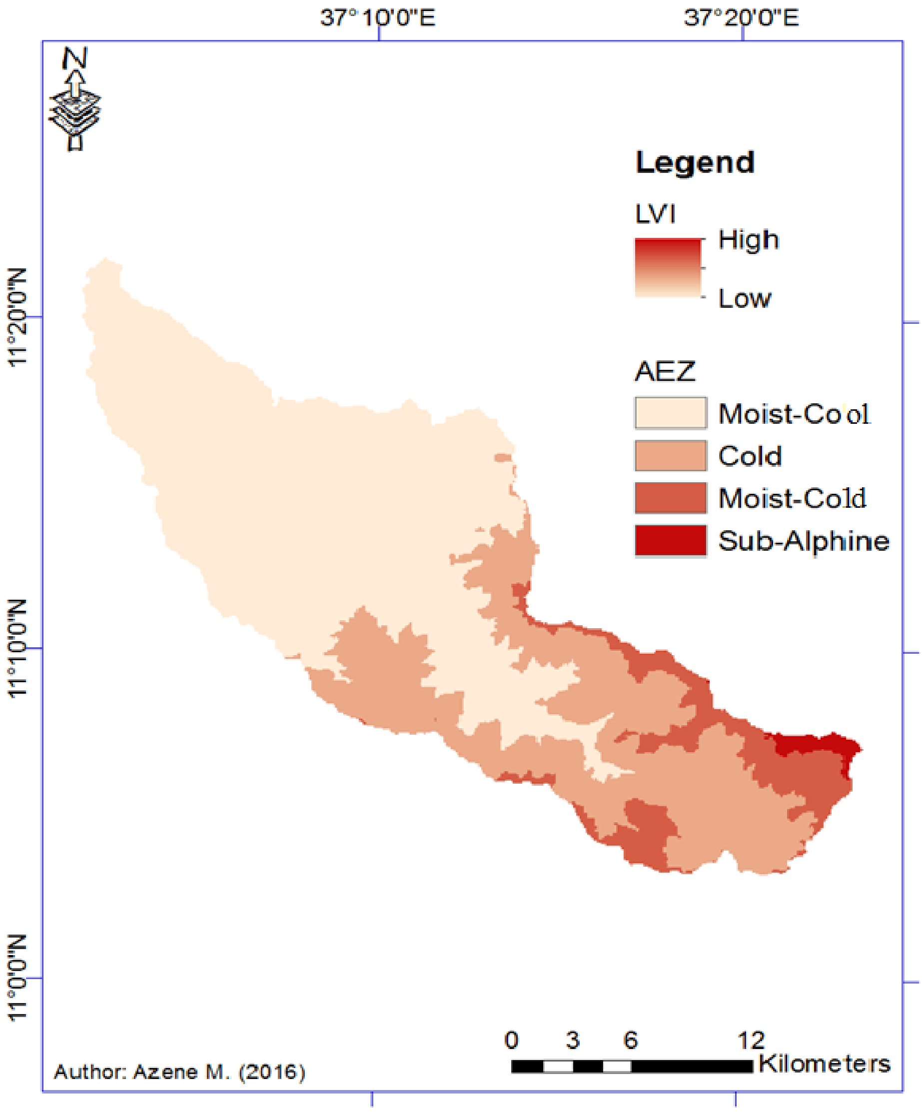


Figure 4.6.2. The level of Livelihood Vulnerability to climate variability among the AEZs of the Jema watershed

Overall this study found out that the livelihood of farmers living in all of the AEZs of the watershed was vulnerable to climate variability. This could be seen from the prevalent subsistence farming system and degraded agroecosystem. In the study conducted in the northern part of the country, Amsalu (2006), Bewket (2003), Endeshaw (2014), Simane et al. (2014) came up with similar findings.

The degree of livelihood vulnerability to climate variability was found higher in the upstream (i.e., in the Moist-Cold and Sub-Alphine AEZs). Simane, et al. (2014) has also found similar spatial pattern of vulnerability across the agroecosystem zones of Choke Mt., north-western part of the country. On the other hand, based on the study conducted in the entire Blue Nile River Basin, the lowest elevation (Kolla AEZ with an elevation of 1500-500 m.a.s.l) was the most vulnerable zone to extreme climate events (Deressa, et al., 2009). The studies conducted by Hahn et al. (2009) in Mozambique and Gain et al. (2012) in Bangladesh has also confirmed the existence of differences in the degree of livelihood vulnerability to climate variability among adjacent districts.

As shown in the result above, variation in the degree of livelihood vulnerability to climate variability was attributed to differences in the three broad factors: exposure to climate variability, adaptive capacity and agroecosystem sensitivity to climate variability. An AEZ with larger degree of adaptive capacity, and lesser sensitivity and exposure is expected to be less vulnerable. It implied that differences in exposure to climate variability alone could not explain differences in the degree of vulnerability to climate variability of a given community or AEZ. That is, the effect of the same level of exposure to climate variability is not equal for the AEZs having different degrees of adaptive capacity and agroecosystem sensitivity.

The effect of climate variability on livelihood vulnerability to climate variability has been explained in terms of food shortage (Degefa, 2005), encroachment to sensitive land segments (Teferi et al., 2013), and forced migration (Ezra and Kiros, 2001). Likewise, this study indicated the existence of the same problems in the years during which there was shorter duration or irregular rainy season. It was true mainly for the fact that the farming system was subsistence that directly depends on rainfed agriculture. Because of shortage of farmland, low level of technology and inappropriate land use system, most households were not capable to produce crops to generate enough income to support their family for more than a year. This problem together with population growth has led farmers to encroach into steep slopes, forest land and wetland. The result implied that the degree of soil erosion and siltation would increase from time to time. The prevalence of poor adaptive capacity and highly sensitive agroecosystem would aggravate forced migration, and intra and inter community conflict for communal grazing land. These problems were more observed in the years of larger RF irregularities, and they were more severe in the upstream than in the downstream.

Similarly, the work of Mesfin (1984) and Pankhurst (1985) confirmed that the northern part of Ethiopia experienced recurring famine (in 1958, in 1966, 1972 to 1974 and 1984 to 85) that was caused by exposure to climatic calamities and institutional factors. Moreover, even in a period of double digit economic growth (MOEF, 2011), severe food shortage has prevailed in some corners of the country in 2015/16 (UNDP, 2007). Variability of mean annual rainfall, onset/end dateof rainy season, and flooding are the major climate risks in the north-western part of the country MOEF (2014). Consequently, unless strategic interventions are made, climatic variability could cause crop failure and related problems especially in the upstream communities of the Jema watershed identified with a weaker adaptive capacity.

This study proved the need to take into account the knowledge and practices of local farmers in participatory designing intervention mechanisms and minimizing the degree of livelihood vulnerability to climate variability. Previous studies conducted in Ethiopia stated that farmers have valuable local knowledge on nature of hazards like climate variability and change (Conway and Schipper, 2011; Endeshaw, 2014) and environmental degradation (Amsalu, 2006; Assefa and Bork, 2015; Hurni, et al., 2005; Teferi, et al., 2016) and its possible adaptation strategies (Degefa, 2005; Deressa et al., 2009; Ezra and Kiros, 2001; Tegene, 2003; Simane, 2014). In the case of the Jema watershed, over the last three decades, farmers with limited support from GOs and/or NGOs have developed various adaptation strategies (Annex 4.5.2) to adapt to the actual climate variability and environmental degradation. As shown in previous studies (MOEF, 2011; and MOARD, 2000), these strategies were also observed in other part of the county where farmer's livelihood depends on mixed crop-livestock farming.

Application of compost (dung) in backyard, horticulture, application of improved seed and livestock hybrid were observed across the watershed (Table 4.6.6). These mechanisms were more practiced in the upstream, where the ecosystem was relatively more degraded, and farmers' livelihood was more vulnerable. Practices like mixed cropping and handicraft, and biogas application were the least employed adaptation strategies all over the watershed. These practices were observed among the least proportion of HDs who live in the upstream.

The observed adaptation strategies (Annex 4.5.2) can be categorized into soil and water conservation, soil nutrient management, agricultural and energy technology, non-farm and mobility. These adaptation strategies have been put into effect both with the help of GOs and/or NGOs, and in the nonexistence of government intervention, so called “autonomous adaptation.”

As presented in Annex 4.5.2, large number of farmers have been involved in physical soil and water conservation activities in the most vulnerable communities, i.e., in the upstream. This happened partly because of the existence of larger proportion of agricultural land in the steeper slope (Figure 3.3), and consequently gully (Annex 4.5.1) which is susceptible for soil loss that need an urgent response both from the local community and GOs/NGOs. On the other hand, due to the presence of more volume of river water and a larger size of irrigable land (Annex 4.5.1), a higher proportion of farmers that adopted rainwater harvesting and river water diversion for small scale irrigation were observed in the least vulnerable AEZ, i.e., in the downstream. Regarding local soil nutrient management mechanisms like mixed cropping and fallowing , larger size of farmers were observed in the upstream, which could be associated with the prevalent severe soil nutrient loss in the farmlands situated in steep slopes (Annex 4.5.1) in the downstream. With respect to application of chemical fertilizer and improved seed and using mirt-stove as response to climate variability and environmental degradation, a larger proportion of HDs were observed in the upstream. The reason for this may be related to the degree of necessity to use more fertilizer and improved seed in steep slopes where soil loss is severe. With respect to adapting livestock hybrid, biogas as a source of energy and alternative off-farm and non-farm livelihood strategies, the downstream took the upper hand. The extent of farmers' seasonal mobility as an adaptation strategy did not show any spatial pattern among the AEZs of the Jema watershed. Relatively, this strategy was observed among a larger proportion of farmers who reside in the Cold and Sub-Alphine AEZs. In the most recent migration history of Ethiopia, farmers' patter of migration has been from highlands to low lands in search of daily labor (Ezra and Kiros, 2001). Some farmers who live in the study watershed were familiarized to move in to lowlands to work as a daily laborer in oil-seeds and coffee commercial farms.

Moreover, the data generated from FGD and field observation (Figure 4.6.3) indicated that there was a limited practice to put into effect area closure and environmental bylaws as an adaptation strategy. But still, social gathering for natural resource conservation and rehabilitation, and other social issues was an evident practice in the study site (Figure 4.6.4). This measure was relatively more implemented in the downstream. In a few communities (for example, in Jema[47] and Gerchech micro-catchments), free grazing was totally forbidden. According to the Rural Land Administration and Land Use Proclamation of the country, land with 30% slope is not recommended for cultivating annual crops (MOEF, 2005). However, encroaching to steep slopes including mountain peaks in pursuit of land for cultivation, grazing, and settlement were also part of adaptation strategies among

[47] The name Jema is also used to refer a name of a micro-catchment (community).

some farmers in the study watershed. This practice was more pronounced in the upstream (Figure 4.6.5). This situation implies that whatever rich experience farmers have in coping and adapting to variability and change of environmental attributes, there were mal-adaptation practices that may hinder efforts of securing sustainable land management. This problem may be linked to shortage of farmland land (Annex 4.5.1) induced by continuous population growth (CSA, 2008) and land degradation, poverty, and prevalent short term attitudes against environment. This argument is in line with the findings of previous studies (Almirew , 2010; Amsalu, 2006; and Simane, et al., 2014) conducted in Ethiopia. The studies indicated that poverty has a part to play in accelerating the degree of environmental degradation.

Furthermore, the FGD and field observation proved that there is a practice of changing crop land into plantation land as an adaptation strategy. This plantation was dominantly covered with a fast growing eucalyptus tree (Figure 4.6.5). The local farmers justified that because of the presence of sever soil nutrient loss, the process of crop production became costly in terms labor and agricultural inputs. As a result, some farmers preferred to change their land use from cropland (that could be grouped under LCC II and III) into plantation land. The practice was more pronounced in the downstream where farmers have access to road and market to supply the primary product of the tree. The situation was motivated by an increasing demand of fire wood and house construction material. It was possible to understand from the FGD data that some farmers in the upstream would have been adopting the same strategy if there had been market access to sell the primary products of the plantation. Similarly, the land use-land cover dynamic study of Moges et al.(2015) conducted in the upper most part of the Blue Nile River Basin was afforested mainly due to the expansion of

Eucalyptus tree into the crop land. This happened because of framers' positive perception about the economic advantage of the tree.

Date: 2015

Figure 4.6. 3. Area closure observed in the Cold AEZ of the Jema watershed

Date: 2015

Figure 4.6. 4. Social gathering made to discuss on natural resource and social issues in the Jema watershed

Figure 4.6.5. Encroachment into steep slopes observed (in 2015) in the Moist-Cool AEZ of the Jema watershed

Date: 2015

Figure 4.6. 6. Land use change from crop land to plantation land in the Jema watershed

Summary of the Section

This section deals with analyzing and discussing spatial differences in indicators and aggregating profiles of livelihood vulnerability to climate variability into three factors: exposure to climate variability, agroecosystem sensitivity and adaptive capacity to climate variability using LVI-IPCC statistic. The cumulative result indicated the existence of relative spatial differences among the AEZs in the factors and livelihood vulnerability as well. Overall, the standard value of vulnerability ranged from 0.052 to 0.130. The degree of vulnerability was larger in the upstream part of the watershed. It was mainly manifested in the spatial differences in the degree of exposure to climate variability. Yet, there was no statistically significant group mean difference in vulnerability and its factors among the AEZs. The result implies that soil erosion, food shortage, forced migration and resource based conflict would be more aggravated in the higher elevation part of the study site. As a way out, farmers have developed adaptation strategies that may be categorized under soil and water conservation, soil nutrient management, agricultural technology, off-farm and mobility. However, there were a mal-adaptation practices that could harm environmental sustainability.

Chapter Five

5. Conclusions and Recommendations

This chapter is devoted to providing concluding remarks and recommendations. The conclusion and recommendation from each chapter are presented separately. Lastly, the chapter ends with indicating potential research areas that need to be addressed in the future.

In terms of the average ATRF, the entire watershed receives enough amount of rainfall to grow the local food crops, cereals and pulses. According to MOARD (2010), an average annual rainfall of 1200 mm would allow cultivating the local food crops. Thus, the observed spatio-temporal variability of ATRF (from 1330 mm to 1670 mm) would not cause a significant disparity in the process of crop production. However, due to variability in duration of rainy season and offset/onset of rainy season, the AEZs situated in the higher elevation (the Moist-Cold and Sub-Alphine AEZs) are disadvantaged in practicing cultivation.

Due to a rise in the monthly mean monthly temperature, the upstream part of the watershed became advantaged in crop diversity and LGP. It was found out that maize and teff cultivation were spreader upwards in the Moist-Cold and Sub-Alphine AEZs respectively. However, this Temp change caused to the overall decline of crop diversity in the entire watershed. For example, in the FGD made in this study, it was discovered that onion, oats, *temezh* (it is a type of barely) and pea production was abandoned by many number of farmers in the upstream, whereas *telba* (*Linmu Usitatisimum Linseed*), barley and *nug* (Guizotia Abyssinica) in the downstream. The rise of Temp also caused to the appearance of malaria, crop pests and weed particularly in the Moist-Cool, Cold and Moist-Cold AEZ. Overall, the aggregated standard value indicates that the degree of exposure to climate variability is larger in the upstream part of the watershed.

In order to determine the sustainability of the farming practice, and securing a sustainable farming system, in river basins like the Upper Blue Nile where a complex topography and wind convection system exists, the spatio-temporal variability of rainfall and temperature data set needs a larger scale analysis. Furthermore, the institutional capacity of forecasting and disseminating agro-meteorological conditions (like the variability of seasonal off-set/on-set of RF, monthly and weekly variability of RF) needs to be more strengthened and more responsible. In this respect, it would also be essential to take actions like revisiting crop calendar in advance.

In order to adapt with the inter-annual variability of onset and end datesof rainy season (shorter rainy season), introducing early maturing crops and improved seeds need to be enhanced widely in the watershed and especially in the higher elevation. As part of adapting with the temperature rise, introducing heat resistant annual crops particularly in the downstream and perennial crops in the upstream could be taken as one strategy. Small scale rainwater harvesting is a potential option for maximizing water availability to domestic animals and enhancing horticulture across the watershed particularly in the downstream.

In terms of limitation of land (soil texture, slope, elevation and mean ATRF), ~3.5 % of the total size of the watershed cannot be used for cultivation at any level of intensity. This segment of land may be used for pasture and forestry. Intense, moderate, and limited cultivation of annual crops can be practiced in 28.56 % (13778.71 ha), 45.74 % (22067.29 ha), 22.16 % (10690.4 ha) of the land respectively. Nevertheless, there is no land segment in the watershed that is appropriate to practice very intensive cultivation. Overall, the degree of land limitation is larger in the higher elevation. In the Sub-Alphine AEZ, 32 ha of the land is cultivated on a potentially non-arable land.

Thus, farmers who settled on LCC-V (3.5 % or 19 km^2 of the land) should change the way of using their land from annual crop production into perennial crop (fruit), pasture or forestry. These land uses can also be made to be more effective through enhancing proper integration of forage legumes with agro-forestry systems; expansion of perennial grasses, bunds, grass strips, contour leveling, terraces, shade trees and waterways. Through expansion of farming practices like rotation of grazing and promotion of stall feeding, the practice of pasture land use and livestock rearing could be more effective. Introducing facilitation mechanisms like payment for ecosystem services including carbon trading may create a good working environment to implement environment friendly adaptation strategies and maximize the adaptive capacity of local communities especially in the upstream. Moreover, the government should be committed to enforce the land use policy through implementing appropriate legal mechanisms.

Regarding LULC type, relatively stating, the proportion of bare land and the proportion of forested and bush lands are larger in the Cold and the Moist-Cold AEZs respectively. Thus, it is possible to conclude that the AEZs of the watershed are subjected to differences in the degree of water percolation and soil erosion. Furthermore, in terms of annual-crop and livestock diversity, there is a declining spatial pattern from the upstream to the downstream. Overall, the aggregated standard value indicates that the degree of agroecosystem sensitivity to climate variability is larger in the upstream part of the watershed.

In order to minimize the degree of ecosystem sensitivity to climate variability (soil erosion, siltation and soil moisture constraint), area closure, agro-forestry, and afforestation/reforestation programs need to be strengthened in the entire watershed. Relatively, more attention needs to be given to the upstream part of the watershed where the agroecosystem is more fragile. The programs have to be guided by scientific land capability class. In addition to LCC, the development practitioners need to depend on supportive studies related to the programs' feasibility, efficiency, contribution to economic growth and equity, and the extent to which they address the future impacts of climate change. As stated by MOEF (2011), agricultural crops are a major source of green house gases (GHG) emissions through the use of fertilizer and through N_2O (Nitrous oxide, commonly known as laughing gas) emissions from crop residues, producing 12 [48]$MtCO_2e$ a year in 2010. It was estimated that this emission value will increase to 60 $MtCO_2e$ a year by 2030 under a business as usual scenario. This estimation would be valid to places like the Jema watershed where the livelihood of people are more dependent in crop production. Hence, avoiding deforestation and adopting higher yielding techniques could be a strategical way out both at local and nation contexts.

[48] $MtCO_2e$ (Million metric tons of carbon dioxide equivalent). This measure can aggregate different green house gases into a single measure, using global warming potentials. One unit of carbon is equivalent to 3.664 units of carbon dioxide.

With respect to the overall adaptive capacity to climate variability, and its profiles (wealth, technology, infrastructure and social capital), all the AEZs of the Jema watershed can be regarded as poor. The observed spatial differences among the AEZs in adaptive capacity were not statistically significant. Moreover, the spatial variation in adaptive capacity among the AEZs was not linear. Yet, in relative terms, the Sub-Alphine AEZ was the poorest with respect to adaptive capacity.

Meanwhile, this study proved that farmers who live in different AEZs have developed various adaptation strategies that need to be enhanced across the larger society. Yet, there was multiple mal-adaptation practices that needs to be corrected with regard to the land capability class and comparative advantage of the AEZs. The practices include are open grazing, encroachment into steep slopes, and changing potential croplands (i.e., land with LCC II, III and IV) into plantation land.

For enhancing the adaptive capacity of the farming communities, emphasis should be given to the expansion of infrastructure, agricultural technology, and strengthening social capital all over the watershed. Mean while, there should be a special concern for expansion of technology adoption and infrastructure in the upstream. Specifically, in order to connect the rural villages with their regular market places, more attention needs to be given to the expansion of gravel road. Similarly, there needs to be a concern for the expansion of green energy sources (like biogas) and access to a reasonable financial credit and saving services in the entire study watershed. Looking at the capability of the land (the proportion of cultivable land), for maximizing land productivity, proper application of chemical fertilizer needs to be maximized primarily in the downstream. Moreover, for securing a sustainable and productive farming system, application of organic fertilizer (manure) has to be enhanced in the entire watershed. Furthermore, alternative off-farm and/or non-farm (poultry, smithing, weaving, petty trading, and daily labor) livelihood strategies need to be diversified primarily in the upstream communities. Such strategies would enable implementing the current national development plan, i.e., transforming from agriculture led into industry led economy. To make it happen, the income generating activities need a strategic support from development programs like the Productive Safety Net.

Over all, a spatial difference was observed in the measured values of factors' index and livelihood vulnerability index among the AEZs. The standardized value of vulnerability to climate variability was found in the range of 0.052 to 0.130. The degree of vulnerability increased as we go from the lower to the upper part of the watershed. This was manifested by a spatial difference in the degree of exposure to climate variability, adaptive capacity and agroecosystem sensitivity to climate variability. Except the case of adaptive capacity, the difference was found to be explained by a spatial linear trend. But still, there was no statistically significant group mean difference in vulnerability and its factors among the AEZs.

For minimizing the degree of vulnerability to climate variability, the practice of strengthening farmers' adaptive capacity and agroecosystem rehabilitation need to be enhanced in the entire watershed. Relatively, more attention is needed to be given to the upstream. To enhance the availability and accessibility of information on the overall profiles of vulnerability, there should be a provision of training on the use of networks to co-ordinate resilience responses between the communities' and the delivery agencies. This process has to be supported with collection and communication of a series of data on the profiles of livelihood vulnerability.

Dissemination of information to the level of the local extension agents can help towards a continuous process of identification and implementation of alternative adaptive mechanisms that go with the specific context of each AEZ.

All concerned sectors of rural development need to strengthen the culture of exercising an integrated action of development including exchanging of reliable information regarding their shared vision. This could help them in terms of identifying more sensitive intervention areas and prioritize the actions to be taken. This process needs to take into account the comparative advantage (land capability and socio-economic capacity) of each the AEZ. Moreover, to make the intervention activities more effective, a full involvement of the local people is needed. If so, there would be a possibility to integrate imported technologies with the local ones for enhancing the degree of communities' resilience. All the mechanisms recommended above could be implemented better through strengthening disaster risk management units and other rural development sectors to facilitate and implement the appropriate adaptation strategies cited above.

Areas of future research

As part of enhancing the efficiency and effectiveness of procedures and tools of investigation, it is wise to direct future research to be engage in filling potential gaps (Deressa et al., 2009; Fussel and Klein 2006;). This study has identified three issues that need to be considered as future research areas in the spatial livelihood vulnerability analysis. One of these is the method of detecting differences in the degree of importance (weight) among indicators identified under various livelihood vulnerability components. The index *"Local Crop Unit"* that is used in this study to differentiate the value of local crops may need improvement. The second issue that needs attention in future research is identifying a larger number indicators of livelihood vulnerability that could make a difference in the communities' exposure to climatic hazard, agroecosystem sensitivity to climate variability, and adaptive capacity. A third point that is critical and which future research works need to give more attention is identification of adaptation options, and their feasibility and implantation mechanisms in a more detailed manner. In studies like this research work, the issues mentioned above would be vital to come up with a finding (i.e., an aggregated vulnerability index value with a maximum harmony among potential indicators that play role in determining the degree of livelihood vulnerability) tailor made to a given study area.

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Appendices

Annex 2. 1. Major adaptation planning zones in Ethiopia

Adaptation planning zones (APZ)	The major source of livelihood				
	Pastoral	Agro-pastoral	Cropping	Horticulture	Mixed
Arid	+	+			
Semi-Arid	+	+			
Semi-Arid Highlands			+		
Sub-Moist North					+
Sub-Moist West			+		+
Sub-Humid Lowlands			+		+
Moist Lowlands	+				
Moist Highlands*				+	+
Tepid Sub-Humid Mid-highlands				+	+
Tepid Humid Mid-highlands				+	+
Humid Central Highlands				+	+
Per Humid	+				
Extreme Highlands				NG	NG
Extreme Moist Highlands*				NG	NG

*: possible adaptation planning zones in this study site; NG: information not given

Adopted from MOEF (2011)

Annex 3. 1. Open-ended questions presented for focus group discussion (FGD)

1. Participants' (households') background information

Questionnaire (household) Code:-----------------;

Date of interview: --------------------------

Time (duration of interview): from------------to------------;

Name and signature of the interviewer:--.

2. Opening and warming section

A. Presenting greetings according to the local custom.
B. Starting with polite small talk about the weather, crop and other related conditions.
C. Showing (telling) respondents the letter recognized by the local authority.
D. Introducing the following points to the interviewee:
    1) As the research is being done by Mintesinot Azene Taye (a PhD Candidate in the Centre for Environment and Development Studies, College of Development Studies, Addis Ababa University, Ethiopia. Cell phone: +251 (0)920519737. E-mail: mintesinotazene@yahoo.com)
    2) As the data will be used for academic purpose (doing PhD dissertation) and possibly for development intervention;
    3) The importance of their genuine response to the study; and
    4) The importance of the output of study to the community with regard to the productivity and sustainability of their farming system.

3. Respondent's (household's) background information

1. Micro-Watershed:----------------------------;Agroecological Zone (Sub Alphine, Moist Cold, Cold, Moist Cool); *Wereda*/District:----------- ; *Kebele/*Sub-District:-----------; and *Got*/village:------------------.

Discussion points related to farmers' livelihood and environment.

1) What are the major sources of income in your locality?

2) Are there farmers who are engaged in non-farm and off-farm activities? If yes, please describe the activities.
3) How many times do you produce crop per year?
4) Are there streams in your locality? If yes, for what purpose do you use them?
5) What are the major crops produced in your locality?
6) How long is the LGP for major crops of your locality?
7) What are the major livestock in your locality?
8) Do you observe any change in the diversity (or type) of crop and livestock compare to the last 15 or 20 years? If yes, please describe the change.
9) Do you observe climate (rainfall and temperature) change in your locality in the last 15 or 20 years? If yes, please describe the direction of change.
10) Do you observe climate variability compare to the last 15 or 20 years? If yes, please describe the differences in duration of rainy season, time of onset and end datesof the rainy season.
11) Do you face shortage of rainfall in your locality?
12) Is flooding a problem in your locality? If yes, how is the severity of flooding compare to the last 15 or 20 years?
13) Do you observe change in the productivity (fertility) of land? If yes, is it improving or declining?
14) Is there any spring that has already been dried up?
15) Do you observe change in forest and bush cover? If yes, is it improving or declining?
16) Is gully a problem in your locality?
17) What do you do to adapt climate change and variability, and land degradation? If there is any.
18) Do you use technologies (fertilizer, selected seed, and hybrid animals)?
19) Do you have access to school, clinic, and Tele-network? If yes, how far is it (minutes)?
20) How much is the price of different types of crops per quintal (this year and in the last two years?
21) How much is the price of different types of livestock per head?
22) How large is (on average) the size of a household's farmland?

Annex 3. 2. Questions Presented for Questionnaire (Structured Interviews)

1. Participants' (households') background information

Questionnaire (household) Code:-----------------;

Date of interview: -------------------------

Time (duration of interview): from------------to------------;

Name and signature of the interviewer:--.

2. Opening and warming section

E. Presenting greetings according to the local custom.
F. Starting with polite small talk about the weather, crop and other related conditions.
G. Showing (telling) respondents the letter recognized by the local authority.
H. Introducing the following points to the interviewee:

5) As the research is being done by Mintesinot Azene Taye (a PhD Candidate in the Centre for Environment and Development Studies, College of Development Studies, Addis Ababa University, Ethiopia. Cell phone: +251 (0)920519737. E-mail: mintesinotazene@yahoo.com)

6) As the data will be used for academic purpose (doing PhD dissertation) and possibly for development intervention;

7) The importance of their genuine response to the study; and

8) The importance of the output of study to the community with regard to the productivity and sustainability of their farming system.

3. Respondent's (household's) background information

2. Micro-Watershed:---------------------------;Agroecological Zone (Sub Alphine, Moist Cold, Cold, Moist Cool); *Wereda*/District:----------- ; *Kebele/*Sub-District:-----------; and *Got*/village:-----------------.
3. Sex 1) Male 2) Female
4. Age 1)38-50 2) 51-65 3) ≥66
5. Marital Status 1) married 2) not married 3) divorced 4) other…………
6. Family size (family members):

No	Age	Sex (in number)		
		Male	Female	Total
7.1	<14 year			
7.2	15-65 years			
7.3	> 65 year			

7. Educational status 1) illiterate 2) able to read and write 3) primary school
4) secondary school 5) higher education 6)other------------------------
8. Do you grow crops in *Belg* (spring) season using rain fall? 1)yes 2)no
9. How many times do you grow crops per year using rain and irrigation? 1)1 2)2 3)3

4. Climate variability/change

10. Have you observed climate variability (compare to the last 20 years) in your locality? 1) yes 2) no 3) no opinion
11. If yes, did you see variability in starting and ending time of rainy season? 1) yes 2) no
12. How did you get the amount of rainfall? 1)increased 2)decreased
    1)increased 2)decreased
13. If your answer is "yes" to climate variability, on average, for how long has the rainy season been staying before 15/20 years? From (beginning, mid, end of -----------month) to (beginning, mid, end of-------month).
14. If your answer is "yes", on average, for how long has the rainy season been staying in the last 5 years? From (beginning, mid, end of -----------month) to (beginning, mid, end of -----------month).
15. If yes to Q11, did you see variability in temperature? 1) yes 2) no 3) no opinion
16. If yes, how did you get the amount of temperature? 1) increased 2) decreased
17. Have you observed any change in the duration of growing season for the local crops? 1)yes 2)no
18. If yes, was it increased or decreased? 1) increased 2) decreased
19. Have you made change in crop type in your farmland? 1)Yes 2) no
20. If yes, recently, which new type crop did you cultivate in your farmland?---------------------------
21. Did you face any, hazard (new in its kind in the last 15/20 years) related to climate change? 1) yes 2) no

22. If yes, please fill the table presented below:

List of hazards	Rank (based on their level of impact)	Frequency of occurrence in the last 7 years	Mau you estimate its impact, in your property, in terms of money/birr?
1) Flooding (heavy rain)			
2) Moisture constraint to grow crops			
3) Unexpected heavy rain			
4) Hail (rain with heavy ice)			
5) Cold (below 0)			
6) Strong wind			
7) Land slide			
8) Plant disease			
9) Infectious animal disease (like------------------------------)			
10) Infectious human disease (like malaria)			
11) Other:----------------------------------			

23. Is there is any opportunity to your faming activity due to the presence of climate change/variability in your locality? Please explain with examples:_________________
____

5. Water resource related questions

24. Is there any water source in your locality/surrounding/micro-catchment? 1)yes 2)no

25. If your answer is yes, please fill the following table.

Type of water source	Distance from home/ farmland (minutes/ hours)	Its adequacy in the dry season of a year			
		For irrigation	For drinking	For animal	For house construction
		Adequacy	Adequacy	Adequacy	Adequacy
1) River		1.inadequate 2.highly-inadequate 3.adequate	1.inadequate 2.highly-inadequate 3.adequate	1.inadequate 2.highly-inadequate 3.adequate	1.inadequate 2.highly-inadequate 3.adequate
2) Spring		1.inadequate 2.highly-inadequate 3.adequate	1.inadequate 2.highly-inadequate 3.adequate	1.inadequate 2.highly-inadequate 3.adequate	1.inadequate 2.highly-inadequate 3.adequate
3) Borehole		1.inadequate 2.highly-inadequate 3.adequate	1.inadequate 2.highly-inadequate 3.adequate	1.inadequate 2.highly-inadequate 3.adequate	1.inadequate 2.highly-inadequate 3.adequate
4) Pipeline		1.inadequate 2.highly-inadequate 3.adequate	1.inadequate 2.highly-inadequate 3.adequate	1.inadequate 2.highly-inadequate 3.adequate	1.inadequate 2.highly-inadequate 3.adequate
5) Other		1.inadequate 2.highly-inadequate 3.adequate	1.inadequate 2.highly-inadequate 3.adequate	1.inadequate 2.highly-inadequate 3.adequate	1.inadequate 2.highly-inadequate 3.adequate

26. How do you evaluate the depth to get underground water (borehole)? 1)increased 2)decreased 3)no change
27. If your answer is increased, how many meters does it require to get underground water (now and in the past)?

13.1. In the past (before 20 years) 1)5-7 m 2)8-10 m 3)11-12m 4)13-15m 5)16-18m 6)other---------

13. 2. Since the last 5 years 1)5-7 m 2)8-10 m 3)11-12m 4)13-15m 5)16-18m 6) other----------

6. Institution and infrastructure related questions

28. Is there any formal information source in your locality? 1)yes 2)no
29. If yes, please give answer to the questions presented in the following table.

Which source do you use?	**Give rank based on their importance**	**About what?**	**How often do you get information in this source?**
1. Radio		1)crop production 2)soil and water conservation 3)livestock 4)marketing of farming products 5)weather forecast and climate variability/change 6)other----------------------------	1) often 2) sometimes 3) rarely 4) not at all
2. Television		1)crop production 2)soil and water conservation 3)livestock 4)marketing of farming products 5)weather forecast and climate variability/change 6)other----------------------------	1) often 2) sometimes 3) rarely 4) not at all
3. Leaflet		1)crop production 2)soil and water conservation 3)livestock 4)marketing of farming products 5)weather forecast and climate variability/change 6)other----------------------------	1) often 2) sometimes 3) rarely 4) not at all
4. Newspaper/ magazine/		1)crop production 2)soil and water conservation 3)livestock 4)marketing of farming products 5)weather forecast and climate variability/change 6)other----------------------------	1) often 2) sometimes 3) rarely 4) not at all

5. Agricultural experts		1)crop production 2)soil and water conservation 3)livestock 4)marketing of farming products 5)weather forecast and climate variability/change 6)other---------------------------	1) often 2) sometimes 3) rarely 4) not at all
6. Neighbors/ friends		1)crop production 2)soil and water conservation 3)livestock 4)marketing of farming products 5)weather forecast and climate variability/ change 6)other----------------------------	1) often 2) sometimes 3) rarely 4) not at all
7. Relatives		1)crop production 2)soil and water conservation 3)livestock 4)marketing of farming products 5)weather forecast and climate variability/change 6)other----------------------------	1) often 2) sometimes 3) rarely 4) not at all
8. Other -------		1)crop production 2)soil and water conservation 3)livestock 4)marketing of farming products 5)weather forecast and climate variability/change 6)other----------------------------	1) often 2) sometimes 3) rarely 4) not at all

30. How often do you use climate related information for your farming system?

1) often 2) sometimes 3) rarely 4) not at all

31. How often do you use market related information?

1) often 2) sometimes 3) rarely 4) not at all

32. How often do you use livestock related information?

1) often 2) sometimes 3) rarely 4) not at all

33. How often do you use soil and water conservation related information?

1) often 2) sometimes 3) rarely 4) not at all

34. How often do you use crop production related information?

1) often 2) sometimes 3) rarely 4) not at all

7. Agricultural extension service

35. Is there any agricultural extension service in your locality? 1) yes 2) no

36. If yes, please give answer to the questions presented in the following table.

For which farming activity?	**Put in order (in which activity did you get better service?)**	**How frequent do you get the service?**	**How far helpful is it?**	**Where do you get the service?**
1) crop production		1) often 2) sometimes 3) rarely 4) not at all	1)very high 2)high 3)less	1) on model site 2) house to house 3) on farm site
2) soil and water conservation		1) often 2) sometimes 3) rarely 4) not at all	1)high 3)less 2)moderate	1) on model site 2) house to house 3) on farm site
3) livestock		1) often 2) sometimes 3) rarely 4) not at all	1)high 2)moderate 3)less	1) on model site 2) house to house 3) on farm site
4) marketing of agricultural products		1) often 2) sometimes 3) rarely 4) not at all	1)high 2)moderate 3)less	1) on model site 2) house to house 3) on farm site
5) other ---------		1) often 2) sometimes 3) rarely 4) not at all	1)high 2)moderate 3)less	1) on model site 2) house to house 3) on farm site

37. How far these services are given in an integrated manner?

1) highly 2) moderately 3) less 4) clash each other

8. Saving and Credit Service

38. Is there any credit and saving institution in your locality? 1)yes 2)no If yes, please fill the table below:

Institutional service	**Do you use the service?**	**Since when (year)?**	**please giv the name of the institution that you use:**	**Their distance from home (hours/minutes)**	**How frequent do you visi the institution?**	**How far do you trust the institution**	**How much do you save /year/six month?**
Credit and saving	1) yes 2) no		1)------------- 2)------------- 3)-------------	1)--------------- 2)--------------- 3)---------------	1)once a month 2)once per 3 months 3)once per 6 months 4)once per a	1) very high 2) high 3) low 4) very low	

					year		

39. If you have an experience in taking credit, for which purpose have you been using it? 1) purchasing food items 2) health treatment 3) trading 4) animal fattening 5) for education expense 6) for buying agriculture input 7) other___________________________
40. If you are not a member of credit and saving association, what is the reason? 1) due to complicated preconditions 2) lack of trust 2) lack of interest 4) Other_

9. Marketing

41. Do you buy/sell agricultural inputs and products in the local market?

    1) yes 2) no
42. If yes, how far accessible in the market? 1)very high 2)high 3)less 4)very less
43. How long does it take to reach this market (hr/minute)? ------------------------------
44. How frequently do you go to this market? 1) once per week 2) once in 2 weeks 3)once in 3 weeks 4)once per month 5) once in 2 months 6) once in 3 months
45. Which mode of transport do you use to go to this market? 1) on foot 2)by car 3) on mule back 4)by cart 5) other--------------------------
46. Is there any road connection to this local market

    1) no 2) yes, seasonal (*tirgia menged*) road 3)yes, all weather gravel road

    4) yes, asphalt road
47. What type of agricultural input do you buy in the local market?

    ____
48. What type of agricultural product do you sell in the market?

    ____
49. What type of agricultural product/input you sell in the market? Please list them in order of order of importance:____
50. Have you ever faced market demand problem to sell your agricultural products/inputs? 1) no 2) yes, very high 3) yes, high 4) yes, less

51. If yes, to which product/impute? ____

9. School service

52. Which level of school is there in your surrounding

1)grade1-4 2) grade5-8 3) grade 9-10 4)11-12 5) there is no at any level

53. If there is school, how far (hour) is it from your home?

1)3hrs 2)2hrs 3)1hr 4)30 minutes 5)------------------

54. Do you send your children to the school? 1) yes 2) no
55. If yes, what grade are they?

Male? 1) grade1-4 2) grade5-8 3)grade 9-10 4)11-12 5)college

Female? 1) grade1-4 2) grade5-8 3) grade 9-10 4)11-12 5) college/university

56. If no, what is the reason?____

10. Telephone and electric power services

57. Is there any telephone service in your locality? 1) yes 2) no
58. If yes, what type of telephone service do you use frequently? 1) fixed wired(house) 2) tele centre 3) fixed wireless 4)mobile 5)other--------
59. Is there any electric power service in your locality? 1. Yes 2. No
60. If your answer is yes, what is the source of the electric power?

1) Hydro 2) Sun 3) Biofuel 4)Wind 5)Other______________________

11. Forest resource and energy source

61. Is there any forest in your locality/micro-catchment? 1) yes 2)no
62. If yes to Q 62, how is the forest developed? 1) by nature 2) by afforestation 3) by reforestation 3)other -------------------
63. If yes to Q 62, what are the dominant tree species in the forest? ---------------------
64. If yes to Q 62, who owns the forest? 1)government 2)local community 3) private 3) no body
65. If yes to Q 62, who is managing/protecting the forest? 1)government 2)the local community 3)NGOs

66. If yes to Q 62, what advantage do you get from the forest?

1) psychological 2) firewood 3) construction material 4) timber 5) nothing

67. If yes, how do you get wood from the forest? 1) sale 2) free

68. How many hours/minutes do you travel on foot to get a mill service?

1)30 minutes 2)1hr 3)2 hrs 4)4hrs 5) other-------------

69. Which one is the source of energy in your locality?

1) Electric power 2) petroleum 3)other-------

70. What is the energy source for cooking your food?

Energy source	**Rank according to usage**	**Suggestion/opinion**
1) Fire wood		
2) Wastes of crop		
3) Dung cake (kubet)		
4) Gas (kerosene)		
5) Biogas		
6) Electric power		
7) Other, specify		

71. Where do you get fire wood, please rank according to usage?

Energy source	**Rank according to usage**	**Suggestion/opinion**
1) Communally owned forest		
2) Privately owned tree land		
3) Naturally grown trees in the farm land		
4) Buying fire wood		
5) Other, specify		

12. Livestock resource

72. For what purpose do you use the waste product (*ebet/korekor*) of livestock?
1) dung cake 2) manure/fertilizer 3)field crop fertilizer 4)other_____________
If it is the case, please put in order of use intensity?

1st------------------2nd ----------------3rd-------------4th--------------

73. Which animal do you use to plough? 1) ox 2) horse 3) donkey

74. Are you accustomed to breed your livestock? 1)yes 2)no

75. What type of livestock do you have/breed? Please fill the table below:

Type of of livestock	Size in number	Their feeding source	Breeding purpose	Which problem do you face in livestock fodder? Put them in rank according to their severity.	Which problem do you face in your livestock breeding? Put them in rank according to their severity.
Ox		1) private grazing land 2) communal grazing land 3) crop residue 4) buying fodd er 5) other_____	1 milk (market) 2) meat (market) 3) ploughing(marke t) 4) domestic use 4) other-------------	1) storage problem 2) shortage of crop residue 3) shortage of grazing land 4) contamination of grazing land/fodder 5)Other________ 6) no	1) Fodder 2) Demand 3) Supply 4) Transport 5) Medication
Cow					
Sheep					
Goat					
Horse					
Mule					
Donkey					
Pig					
Other					

12. Social Capital

76. In your locality, how is the level of cooperation (in terms of labor) to carry out farming activities among neighbors?

    1) very strong 2) strong 3) good 4) weak 5) very weak

77. In your locality, how is the level of cooperation (in terms of labor) to carry out farming activities among relatives?

    1) very strong 2) strong 3) good 4) weak 5) very weak

78. In your locality, how is the level of sharing (borrowing/lending) farming resources among neighbors? 1) very strong 2) strong 3) good 4) weak 5) very weak

79. In your locality, how is the level of sharing (borrowing/lending) farming resources among relatives? 1) very strong 2) strong 3) good 4) weak 5) very weak

80. What kind of local/informal (established by the local farmers) institutions are there in your locality? 1)peace and security 2) religious practices and ceremonies

3)external relationship for various purposes 4)natural resources management 5)edir 6)ekub 7)others------------------------------- 8)none

81. In which informal organization, are you registered as a member? What kind of local/informal (established by the local farmers) institutions are there in your locality? 1) peace and security 2)religious practices and ceremonies 3)external relationship for various purposes 4)natural resources management 5)edir 6)ekub 7)others------------------------------------- 8) none

82. How do you rate the culture of lending/borrowing money among local individuals?

    1)very high 2)high 3)less 4)very less 5)no borrowing/lending at all

83. How do you rate the degree of resource based conflict among local people? 1)very high 2)high 3)less 4)very less 5)no conflict at all

84. How many religious holidays (where farming activities are restricted) are there per month? 1)4 2)8 3)10 4)10 5)11 6)12 7)13 8)other------------

85. For how many days do you become free of farming activities per month? 1) on all holidays 2)on some holidays 3) I work on all days

86. What, other than farming activities, do you do on holidays? 1)fencing 2)marketing 3)meeting 4)others________________________________

13. Human Capital

87. How many labor forces is enough in farming season for farming activities of your family? 1)4 2)5 3)6 4)7 5)other-----

88. How do you rate the adequacy of labor force in your family for your various farming activities in farming season 1) more than enough 2) enough 3) there is shortage 4) there is very high shortage

89. If there is shortage of labor in your family, what is the reason? 1) having less family size 2)death of family member/s 3) my family member/s is/are permanently sick 2)seasonal migration to urban areas 3)seasonal migration to rural areas 4)permanent migration to urban areas 5)permanent migration to rural areas

90. What do you do when you face labor shortage (if it is the case)? 1) employing daily laborer 2)employing labor in kenja system 3)seeking for support from relatives/neighbours 4)renting the land 5)other________________________

91. How much birr /day do you pay for a daily laborer (if it is the case)?

1)20 2)25 3)30 4)35 5)other------------------

92. If you apply kenja, how much (out of the total product) do you pay for kenja?

1)1/2 2)1/3 3)1/4 4)other-----------

93. If you rent your land, how much birr do you rent your farmland per timad/year?

1)500 2)1000 3)1500 4)2000 5)2500 6) other---------------------

94. Is there any handicap/disabled person in your family? 1. Yes 2. No

95. If your answer is yes how many of them?________________________________

96. Is there any member of your family always sick? 1)yes 2) no

97. If your answer is yes, how many of them?_______________________________

98. What type of disease is prevalent?_____________________________________

99. In your locality, how you evaluate population growth?

1) highly increased 2)increased 3)no change 4)decreasing?

14. Land resource

100. Are you active in farming activities currently? 1)yes 2)no

101. If no, what is the reason?

1)age 2)health 3)employing others 4)shifting into non-farm activities 5)other---

102. Do you have your own farmland? 1)yes 2) no

103. If yes, what is its size in *Timad* (one fourth of a hectare)?

104. Cultivated land 1)2 2)3 3)4 4)5 5)6 6)7 7)other------------------

105. Grass and woodland 1)2 2)3 3)4 4)5 5)6 6)7 7)other-------------------

106. backyard 1)2 2)3 3)4 4)5 5)6 6)7 7)other--------------------

107. Irrigated Land 1)2 2)3 3)4 4)5 5)6 6)7 7)other----------------

108. Plantation land 1)2 2)3 3)4 4)5 5)6 6)7 7)other---------------

109. Other---------------- 1)2 2)3 3)4 4)5 5)6 6)7 7)other---------------

110. How is the size of your farmland? 1)increasing 2)decreasing 3)no change

111. If your answer is decreasing, what are the reasons for the decrement of you cultivated land?

1) degradation of land and increase of rangeland
2) distribution of cultivated land in the family
3) redistribution of cultivated land among the community
4) other____

85. If your answer is increased, what could be the reason?

1)deforestation 2) farming of mountainous and hill lands

3)redistribution of cultivated land 4) other_______________

86. How is the total amount of production in your home?

1)increasing 2)decreasing 3)no change

87. If your answer is increased, what could be the reason? 1) application of more fertilizer 2)application of more selected seed 3) application of pesticide 4) improvement of soil fertility 5)_________________________

88. Please put your reasons in order of their importance 1st----------2nd--------3rd-------

89. If your answer is decreased, what could be the reason?

1)soil degradation 2)crop disease (pest) 3) flood

4)drought 5)rainfall irregularity 6)other__________________

90. Please put your reasons in order of their importance 1st--------2nd--------3rd-------

91. How is the productivity of your cultivated land per hectare? 1) increased 2) decreased 3)no change

92. If your answer is increased, what are the reasons for the improvement of land productivity of your cultivated land?

1) application of more fertilizer 2)application of more selected seed

3) application of pesticide 4) improvement of soil fertility

5)____

93. Please put your reasons in order of their importance

94. 1st-------------------------------2nd-------------------------3rd-------------------------

95. If your answer is decreased, what are the reasons for the decline of productivity of your cultivated land?

1) land degradation 2)rainfall variability 3) drought

4) pests and crop diseases 5) Other___________________

15. Crop production

96. How is the crop production and its input used according to the type of crop? Please fill the following table:

Type of	Size of land	Production	Utilization of fertilizer

crop produced	in *Timad*	per *Timad*	Type of chemical fertilizer and its amount (in KG) per year	Natural fertilizer and its amount (in KG) per year	Special crop species	Local crop species
			Total amount in kg per year-------	Total amount in kg per year-----		

Timad= one fourth of a hectare

16. Respondents' income source

97. Please give answer to the following questions related to actual income sources:

Possible income source	**Rank based on their importance**	**As an income source, how much does it cover?**
112. Crop production		1) 1(100%) 2)½ 3)1/3 4) ¼
113. Livestock (cow/ox, sheep, goat, horse, or donkey) rearing		1) 1(100%) 2) ½ 3)1/3 4) ¼
114. Poultry		1) 1(100%) 2)½ 3)1/3 4) ¼
115. Forestry (plantation for market)		1) 1(100%) 2) ½ 3)1/3 4) ¼
116. Fruit production		1) 1(100%) 2)½ 3)1/3 4) ¼
117. Petty trading		1) 1(100%) 2) ½ 3)1/3 4) ¼
118. Handicraft (blacksmith, carpenter, making cloth, making furniture, other-----------------		1) 1(100%) 2)½ 3)1/3 4) ¼
119. Bee-keeping		1) 1(100%) 2) ½ 3)1/3 4) ¼
120. Seasonal migration (daily labor)		1) 1(100%) 2)½ 3)1/3 4) ¼
121. Remittance		1) 1(100%) 2) ½ 3)1/3 4) ¼
122. Civil servant		1) 1(100%) 2)½ 3)1/3 4) ¼
123. Aid from NGOs/GOs		1) 1(100%) 2) ½ 3)1/3 4) ¼
124. Other--------------------		1) 1(100%) 2)½ 3)1/3 4) ¼

Annex 3. 3. Sample size (HD participants) considered in each of the sampling unit

Moist-Cool		Cold		Moist-Cold		Sub-Alphine	
Cluster's Name	Sample size	Cluster's Name	Sample size	Cluster's Name	Sample size	Cluster's Name	Sample size
Abradi	21	Ateta	19	Jema	15	Adama	13
Aguga	22	Jema (Cold)	21	Lay Guder	19		
Argedif	20	Nanina	17	Washaw	15		
Arib-Gebeya	24	Tikur Wuha	18				
Asabila	23	Tinda	21				
Gerchech	21	Yeba	18				
Jankuala	20						
Jema	23						
Marzeneb	26						
Tumha	24						

In this table, Jema refers to the name of a micro-watershed (village) within the larger Jema watershed. The sample size was ~30% of each sampling frame.

Annex 3. 4. Sampling frame (a total number of households) in each of the sampling unit (villages or micro-catchments)

Moist-Cool		Cold		Moist-Cold		Sub-Alphine	
Cluster's Name	Sampling Frame	Cluster's Name	Sampling Frame	Cluster's Name	Sampling Frame	Cluster's Name	Sampling Frame
Abradi	67	Ateta	64	Jema	51	Adama	39
Aguga	73	Jema	69	Lay Guder	62		
Argedif	68	Nanina	55	Washaw	49		
Arib-Gebeya	80	Tikur Wuha	59				
Asabila	75	Tinda	71				
Gerchech	69	Yeba	59				
Jankuala	66						
Jema	77						
Marzeneb	85						
Tumha	80						

Annex 4.5. 1. The indexed value for the indicators and profiles of livelihood vulnerability to climate variability.

Profiles	Indicators	Observed values across the Watershed		Indexed values among the AEZs			
		Maximum	Minimum	Moist-Cool	Cold	Moist-Cold	Sub-Alphine
Climate variability	Variability in onset time (being late) of rainy season in the last 15 or 20 years (in month).	1.50	0.50	0.500	0.500	0.750	0.750
	Variability in end date(earlier) of rainy season in the last 15 or 20 years (in month).	2.00	0.75	0.400	0.600	0.800	0.800
	Variability in duration of rainy season (in month).	3.50	1.00	0.100	0.400	0.800	0.800
	Standard deviation (SD) of the average ATRF (in mm)	189.88	109.43	0.569	0.440	0.297	0.297
	Standard deviation (SD) of the average daily max temp by month (in ^{0}C).	3.71	0.85	0.617	0.662	0.702	0.702
	Standard deviation (SD) of the average daily min temp by month (in ^{0}C).	3.82	0.83	0.355	0.310	0.253	0.253
	Average value			0.424	0.485	0.600	0.600
Agroecosystem sensitivity to climate variability	Proportionof arable land-LCC II (in km^2).	100.00	0.00	0.025	1.000	0.691	0.417
	Proportionof arable land-LCC III (in km^2).	100.00	0.00	0.032	0.024	0.082	0.100
	Proportionof arable land-LCC IV (in km^2).	100.00	0.00	0.167	0.039	0.034	0.031
	Proportionof arable land-LCC V (in km^2).	100.00	0.00	1.000	1.000	0.052	0.057
	Proportionof bush land (in km^2).	100.00	0.00	0.926	0.082	0.936	0.886
	Proportionof forest land (in km^2).	100.00	0.00	0.987	0.239	0.969	0.986
	Proportionof water body, stream water (in km^2).	100.00	0.00	0.998	0.855	0.999	0.999
	Accessibility (in minutes) of spring/stream water.	2.00	0.00	0.676	0.585	0.552	0.518
	Average ATRF (in	1720.00	1300.00	0.001	0.001	0.001	0.001

	terms of rain water harvesting potential) (in mm).						
	Livestock diversity index.	7.00	1.00	0.194	0.196	0.243	0.251
	Crop diversity index.	5.00	2.00	0.222	0.222	0.250	0.323
	Proportionof bare land (in km^2).	100.00	0.00	0.001	0.001	0.002	0.001
	Gully as a major environmental problem (in qualitative scale).	100.00	0.00	0.070	0.857	0.905	1.000
	LGP for major growing crops (in week).	7.00	3.00	0.000	0.250	0.625	0.875
	Average value			0.384	0.381	0.453	0.460
Infrastructure	HDs (%) having access to road (weather or gravel) to go to their regular market.	100.00	0.00	0.365	0.123	0.158	0.077
	HDs (%) having access to electricity (power).	100.00	0.00	0.018	0.000	0.000	0.000
	Distance to access regular market (in minute).	300.00	10.00	0.014	0.008	0.010	0.010
	Distance to access health center (in minute).	210.00	10.00	0.016	0.010	0.016	0.015
	Distance to access schools (grade 1-4, 5-8, and 9-10) (in minute).	390.00	10.00	0.014	0.009	0.010	0.012
	Distance to access telephone service (tele-network) (in minute).	150.00	0.00	0.065	0.027	0.033	0.049
	Average value			0.082	0.029	0.038	0.027
Wealth	Total agricultural land size *(in *Kada)*	16.00	0.25	0.354	0.281	0.292	0.336
	Irrigable land size (in *kada).*	5.00	0.00	0.059	0.026	0.078	0.093
	Size of ox per HD (count).	4.00	0.00	0.276	0.240	0.201	0.215
	Size of caw (count).	5.00	0.00	0.181	0.135	0.098	0.097
	Size of heifer (count).	4.00	0.00	0.142	0.112	0.070	0.027
	Size of bull (count).	4.00	0.00	0.168	0.128	0.079	0.067
	Size of sheep and/or goat (count).	17.00	0.00	0.012	0.015	0.033	0.053
	Size of mule (count).	2.00	0.00	0.056	0.040	0.166	0.242
	Size of horse (count).	3.00	0.00	0.002	0.008	0.007	0.062
	Size of asses (donkey) (count).	5.00	0.00	0.112	0.112	0.133	0.077
	Size of hen (count).	25.00	0.00	0.001	0.001	0.002	0.002
	Income from barley (in **birr*).	20.00	1.00	0.040	0.208	0.149	0.149

	Income from potato (in birr).	25.00	1.00	0.031	0.063	0.162	0.162
	Income from maize (in birr).	30.00	0.00	0.133	0.106	0.063	0.000
	Income from *teff* (Eragrostis) (in birr).	6.00	0.00	0.790	0.353	0.351	0.000
	Income from pea (in birr).	4.00	0.50	0.332	0.451	0.765	0.667
	Income from *nug* (Guizotia Abyssinica) (in birr).	5.00	0.00	0.571	0.000	0.000	0.000
	Income from red onion (in birr).	7.00	0.00	0.256	0.224	0.336	0.334
	Income from non-farm (handicrafts) practices (in birr).	100.00	0.00	0.099	0.136	0.148	0.077
	Income from off-farm (seasonal migration-daily labor) (in birr).	100.00	0.00	0.120	0.265	0.115	0.077
	Average value			0.187	0.145	0.162	0.137
Agricultural Technology	Proportion of HDs who were using chemical fertilizer (*DA & urea).	100.00	0.00	0.822	0.787	0.815	0.846
	Proportion of HDs who were using improved seed.	100.00	0.00	0.863	0.839	0.860	0.923
	Proportion of HDs who domesticated improved livestock hybrid.	100.00	0.00	0.548	0.531	0.367	0.308
	Proportion of HDs who were using biogas as a source of energy.	100.00	0.00	0.174	0.159	0.128	0.000
	Proportion of HDs who were using mirt-stove as a source of energy.	100.00	0.00	0.330	0.331	0.347	0.462
	Average value			0.620	0.595	0.601	0.590
Social- Capital	Proportion of literate HDs.	100.00	0.00	0.380	0.331	0.365	0.385
	Proportion of family members who were attending school.	100.00	0.00	0.654	0.596	0.609	0.538
	Proportion of family members at working age (15-65).	100.00	0.00	0.546	0.536	0.587	0.692
	HDs (%) experienced in taking credit from local financial institution.	100.00	0.00	0.417	0.378	0.403	0.308
	HDs (%) experienced in social gathering for natural resource conservation.	100.00	0.00	1.000	1.000	1.000	1.000

	Regular number of working days in a month.	25.00	13.00	0.433	0.475	0.425	0.199
	Average value			0.572	0.553	0.565	0.520
	Adaptive capacity to climate variability			0.277	0.246	0.248	0.235
	Livelihood vulnerability to climate variability			0.052	0.064	0.126	0.130

**kada:* one fourth of a hectare; *1 birr=$0.048USD, *DAP: diammonium phosphate. The analysis was done at a confidence interval of 95%, and a missing data of 3%.

Adaptation strategies	% of HDs observed within each AEZs				
	Moist-Cold	Cold	Moist-Cool	Sub-Alphine	Jema watershed
Constructing soil-bund	64.7	76.2	60.0	30.8	57.9
Constructing soil-stone bund	39.3	37.1	39.5	69.2	46.3
Application of stone-bund	11.2	24.0	45.9	57.3	34.6
Using river water for irrigation	40.1	15.2	2.5	57.3	28.8
Harvesting rain water	8.7	1.0	1.5	57.3	17.1
Employing fallowing (for 1 cropping season)	2.5	2.9	2.5	57.3	16.3
Employing crop rotation	60.0	25.0	15.0	57.3	39.3
Employing mixed-cropping	11.2	3.8	0.0	0.0	3.8
Using biogas	17.4	15.9	12.8	7.1	13.3
Using mirt-stove	32.9	34.0	35.0	42.0	36.0
Application of improved seed	84.3	82.9	85.0	85.0	84.3
Application of chemical fertilizer (diammonium phosphate-DAP* & Urea)	81.2	77.7	80.5	84.7	81.0
Hybridize livestock	56.0	54.3	35.6	32.1	44.5
Application of compost (dunk)	90.1	93.2	95.0	96.0	93.6
Being a member of saving and credit association.	41.7	38.8	48.0	28.6	39.3
Handicraft (weaving and smithing)	7.9	7.6	3.8	3.8	5.8
Seasonal migration (working as daily laborer)	12.0	29.5	12.5	7.0	15.3
Proportion of HDs who employed the strategies indicated above	38.924	36.4	33.8	45.5	

Annex 4.5.2. Adaptation strategies observed (% of HD within each AEZ) in the Jema watershed