Vulnerability to the changing climate and the quest for livelihood resilience: Agro-ecology based analysis in Wolaita *Zone*, Southern Ethiopia

Befikadu Esayas Amphune

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

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

Addis Ababa University

Addis Ababa, Ethiopia

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June 2019

Declaration

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

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Place: Addis Ababa

Data of submission: ______________________

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

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Dissertation Approval

Addis Ababa University

School of Graduate Studies

This is to certify that the dissertation prepared by Befikadu Esayas Amphune entitled "**Vulnerability to the changing climate and the quest for livelihood resilience: Agro-ecology based analysis in Wolaita *Zone*, Southern Ethiopia**" and submitted in fulfillment of the requirement for the Degree of Doctor of Philosophy (Environment and Development Studies) compiles with the regulations of the University and meets the accepted standards with respect to originality and quality.

Signed by the Examining Committee:

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Chair, Examining Committee Signature Date

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Chair of the Department or Graduate Program Coordinator

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Dedication

This Ph.D. work is dedicated to the most vulnerable farm households striving in the face of the changing climate across Wolaita *Zone*, to my late stepfather-Bogale Wolde (*Boge*) whom I lost in November 2018 and my beloved mother Begeme Wole for her unconditional love and moral encouragementsthroughout the Ph.D.study.

Vulnerability to the changing climate and the quest for livelihood resilience: Agro-ecology based analysis in Wolaita *Zone*, Southern Ethiopia

General abstract

Building livelihood resilience requires reducing exposure and sensitivity while improving capacitates to absorb, adapt, and transform from recurring climate shocks. The general objective of this study was to explore households'livelihood vulnerability conditions tothe changing climate and investigate livelihood resilience from absorptive, adaptive, and transformative perspectives in the three agro-ecological Zones of Wolaita Zone, Southern Ethiopia. Being governed by the pragmatist philosophical view, the study employed a convergent parallel mixed research design whereby most of the study objectives were centered on quantitative data collected through multistage sampling techniques from 403 farm households. Gridded time series data were also obtained from the National Meteorological Agency of Ethiopia for the years between 1983 and 2014. Purposively selected 11 focus group discussions, 15 key informant interviews, and personal observations were used to complement both the survey and the meteorological data. The livelihood vulnerability approach framed by the Intergovernmental Panel on Climate Change was tailored for the agro-ecology specific vulnerability analysis whereas the livelihood analysis was rooted in the three-dimensional resilience framework consisting of absorptive, adaptive and transformative capacities. The study was based on climate trend analysis methods, including World Meteorological Organization-Expert Team on Climate Change Detection and Indices, and Non-Parametric-Sen's Slope Estimator and Mann–Kendall's trend tests, Standardized Rainfall Anomaly, and Precipitation Concentration Index. The econometric models employed include Binary Logit, Ordinary Least Square, and Quantile Regression. The results show that the three agro-ecological Zones have experienced both positive and negative trends of change in temperature extremes. Warm extremes are increasing, whereascold extremes are decreasing, suggesting considerable changes in the agro-ecological zones. Similarly, a consistently positive trend was observed in the annual minimum temperature in all agro-ecological Zones while the annual maximum temperature trend was positive in all except the midland agro-ecology. An upward trend in the annual total rainfall was recorded in the midland while it was a non-significant downward trend in the other agro-ecological Zones. Over 60 % of farmers perceived increasing temperature and decreasing rainfall across the agro-ecological zones. Farmers' climate change perceptions are significantly influenced by their access to climate and market information, agro-ecology, education, agricultural input, and village market distance. The livelihood vulnerability analysis suggests that lowland agro-ecology has relatively a higher exposure and sensitivity to climate shocks with a comparatively limited adaptive capacity. On the contrary, the midland agro-ecology unveils the lowest vulnerability with a relatively lower perceived exposure and a higher adaptive capacity. The quantile regression shows that education, family size, food-secure months, use of soil and water conservation, and role in the community are the major determinants of household's level of resilience. Therefore, the study recommendsencouraging the practice of drought-tolerant varieties, high yield crops, practice small-scale irrigation, and agroforestry that fit the specific agro-ecology. It is also suggested to capitalize on resilience building

schemes, such as the design of viable livelihood diversification strategies, promote agricultural cooperatives, extensions services, inputand output markets, and reinforce the early warning system and disaster risk management to reduce further vulnerability to climate impacts and improve their livelihood resilience capacities.
Keywords: *Agro-ecology, climate extremes, livelihood vulnerability, livelihood resilience, perception, shocks, Wolaita Zone.*

List of original papers

This dissertation is based on the following four original papers, which are listed from 1-4.

Paper 1. Esayas, B., Simane, B., Teferi, E., Ongoma, V., & Tefera, N. (2018). Trends in extreme climate events over three agro-ecological *Zone*s of Southern Ethiopia. *Advances in Meteorology*, 2018, ID 7354157.doi.10.1155/2018/7354157 (Published).

Paper 2. Esayas, B., Simane, B., Teferi, E., Ongoma, V., & Tefera, N. (2019a). Climate variability and farmers' perception in Southern Ethiopia. *Advances in Meteorology*. *Special Issue on Climate Risk Assessment, Coping, and Adaptation*2019, ID 7341465. doi.org/10.1155/2019/7341465(Published).

Paper 3. Esayas, B., Simane, B., & Tefera, N. (2019b). Farmers' livelihood vulnerability to climate variability and change over agro-ecological *Zone*s in Southern Ethiopia. *Journal of Ecological Processes*, Springer(Under review).

Paper 4. Esayas, B., Simane, B., & Tefera, N. (2019c). Livelihood resilience capacities and the determinants: Evidence from three agro-ecological *Zone*s of Southern Ethiopia. *Journal of Agricultural and Food Economics,* Springer(Revision submitted).

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Acronyms

ABCI	Absorptive Capacity Index
ACCRA	Africa Climate Change Resilience Alliance
ADCI	Adaptive Capacity Index
ADR	Age Dependency Ratio
AEZs	Agro-Ecological *Zone*s
AfDB	African Development Bank
ANOVA	Analysis of Variance
ATmax	Annual Maximum Temperature
ATmin	Annual Minimum Temperature
CC	Climate Change
CCP	Climate Change Perception
CIA	Central Intelligence Agency
CISI	Climate-Induced Shocks Index
CO_2	Carbon dioxide
CSA	Central Statistics Authority
CSA	Climate-Smart Agriculture
CS-Pro	Census and Survey Processing System
CV	Coefficient of Variation
DAP	Diammonium Phosphate
DFID	Department for International Development
EPA	Environment Protection Authority

EPCC	Ethiopian Panel on Climate Change
ETCCDI	Expert Team on Climate Change Detection and Indices
EWS	Early Warning System
FAO	Food and Agricultural Organization
FDRE	Federal Democratic Republic of Ethiopia
FEDD	Finance and Economic Development main Department
FGD	Focus Group Discussion
FO	Field Observation
FRCI	Future Resilience Capacity Index
FSIN	Food Security Information Network
GDP	Gross Domestic Product
GHGs	Greenhouse Gases
GIS	Geographic Information System
HABP	Household Asset Building Program
HAI	Household Asset Index
HDDS	Household Dietary Diversity Score
HDI	Human Development Index
HHs	Households
HL	Highland
HRI	Household Resilience index
IAEA	International Atomic Energy Agency
IFPRI	International Food Policy Research Institute
IPCC	Intergovernmental Panel on Climate Change
IRDR	Integrated Research on Disaster Risk
KII	Key Informant Interviews
KM	Kilometer
LDI	Livelihood Diversification Index
LIV-IPCC	Livelihood Vulnerability Index-Intergovernmental Panel on Climate Change
LL	Lowland
LRI	Livelihood Resilience Index

LSMS	Ethiopian Living Standards and Measurement Survey
LVI	Livelihood Vulnerability Index
MCPP	Monthly Consumption Per Capita
ML	Midland
MoA	Ministry of Agriculture
NCA	National Climate Assessment
NGOs	Non-Governmental Organizations
NMA	National Meteorological Agency
OLS	Ordinary Least Squares
PAI	Productive Assets Index
PRIME	Pastoralist Areas Resilience Improvement and Market Expansion
PC	Principal Component
PCA	Principal Component Analysis
PCI	Precipitation Concentration Index
PhD	Doctor of Philosophy
PPP	Purchasing Power Parity
PRA	Pressure Release Model
PRCI	Past Resilience Capacity Index
PSNP	Productive Safety Net Program
QR	Quantile Regression
SDGs	Sustainable Development Goals
SER	Socio-Ecological Resilience
SES	Socio-Ecological System
SI	Sensitivity Index
SLF	Sustainable Livelihood Framework
SNNP	Southern Nations and Nationalities People
SNNPRS	Southern Nation Nationalities and Peoples Regional State
SPSS	Statistical Package for Social Sciences
HSQ	Household Survey Questionnaire
SD	Standard Deviation
SRA	Standardized Rainfall Anomaly

SSA	Sub-Saharan Africa (SAA)
SWC	Soil Water Conservation
TC	Transformative Capacity
TCI	Transformative Capacity Index
TLU	Total Livestock Unit
Tmax	Maximum Temperature
Tmin	Minimum Temperature
TRF	Total Rain Fall
UN	United Nations
UNDP	United Nations Development Program
UNFCCC	United Nations Framework Convention on Climate Change
UN-ISDR	United Nations International Strategy for Disaster Reduction
USAID	United States Agency for International Development
USD	United States Dollar
WBGU	German Advisory Council on Global Change
WFP	World Food Program
WMO	World Meteorological Organization
WZFED	Wolaita *Zone* Finance and Economic Development

Chapter one

1 General introduction

1.1 Background of the study

> *"Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850."* (IPCC, 2014 p.2).

Climate change is the most pressing environmental challenge facing the world today (IAEA, 2015). The IPCC (2007) report indicated that climate change (CC) is occurring in the form of temperature increases, changes in precipitation and sea-level rise, and the intensification of natural hazards, such as storms, floods, droughts, and landslides. A report suggested that between 1880 and 2012, globally averaged surface temperature increased by 0.85°C(IAEA, 2015).The latest IPCC report issued in 2014 discloses a bulk of new evidence showing that climate system of the Earth is changing due to increasing concentrations of greenhouse gases (GHGs), particularly of carbon dioxide (CO_2). This is mainly linked to human activities', mostly the burning of fossil fuels and land-use change (IPCC, 2014).

In the 2012 IPCC report, it is indicated that climate change is inevitable and will result in changes in climate variability and the frequency, intensity, spatial extent, duration, and timing of extreme weather and climate events (IPCC, 2012). Recent studies have suggested that changes in the occurrence and severity of extreme climate events along with the variability of weather patterns will have significant consequences for human and natural systems (IPCC, 2012; IPCC, 2014; Thornton *et al*., 2014). Indeed, climate change impacts are real and being experienced in various ways in many parts of the world (Adger *et al*., 2011; IPCC, 2014). Scholars also suggest that there are many pieces of evidence of the change in global climate and projections pointed out that the rate of change will likely increase (IPCC, 2007; Eshetu *et al*., 2014; IPCC, 2014).

Climate change is also projected to increase the scale and scope of the impacts of many natural hazards on local populations (IPCC, 2014; NCA, 2014). In this case, even though Africa's contribution to world's total GHG emission is only less than 3% (IPCC, 2007), the continent is vulnerable to impacts of climate variability and change (Lobell, Banziger, Magorokosho, &

Vivek, 2011). The vulnerability is mainly related to its high exposure and low adaptive capacity (IPCC, 2014).

Similarly, Eastern Africa is getting drier due to rise in sea surface temperature of the Indian Ocean (Williams *et al*., 2012) which in turn has brought exceptional challenges to crop cultivation and livestock production (Kassie *et al*., 2013). Various studies have documented the historical trends of climate variability and change in Ethiopia. For example, an increase in mean annual temperature of 1.3°C from 1960 to 2006 with 0.2°C to 0.28°C per decade was recorded (Keller, 2009; Eshetu *et al*., 2014). The annual minimum temperature increased by about 0.37°C every decade between 1951 and 2006 (McSweeney, New, & Lizcano, 2008). The IPCC report discloses that the negative impacts of climate trends have been more common than positive ones (IPCC, 2013). A projection suggests that Ethiopia will experience a 1.7-2.1ºC increase in the mean temperature by 2050 (EPA, 2012). Average annual temperatures are expected to rise 3.1°C by 2060, and 5.1°C by 2090, while precipitation is projected to decrease from an annual average of 2.04 mm/day (1961-1990) to 1.97 mm/day (2070-2099) with a collective decline in rainfall by 25.5 mm/year (Kidanu, Rovin, & Hardee-Cleaveland, 2009).

Given the observed and projected impacts of climate change on people, livelihoods and the ecosystem in different geographies of scale, including Ethiopia, the concept of ‘climate change vulnerability’ is relevant to better understand the cause or effect relationships associated with climate change and its adverse effects on people, economic sectors and socio-ecological systems (IPCC, 2014). It is a complex and multidimensional concept with slight consensus across disciplines vis-à-vis how it should be understood, considered and studied (Raemaekers & Sowman, 2015). In the context of climate change, vulnerability is often regarded as a function of exposure to a hazard, sensitivity to the hazard, and the ability to respond to the hazard (Adger, 2006; Smit & Wandel, 2006; Parry *et al*., 2007).

The 2014 New Climate Economy Report warns that the occurrence of disaster in years to come is inevitable if remedial solutions towards limiting global warming to 2°C (compared to pre-industrial times) is not taken promptly (Kreft, Eckstein, Dorsch, & Fischer, 2016). Furthermore, the vision stated in the SDGs[1]indicates that if shocks and stressed are not solved timely, the problems will inevitably impact people (Bahadur, Lovell, Wilkinson, & Tanner, 2015a). This is mainly because many of the adverse effects will disproportionately impact people in developing countries where vulnerability to climate change is predominantly high (Kreft *et al*., 2016).

In spite of mitigation and adaptation efforts implemented so far in different parts of the world by different development partners in collaboration with the governments, human and natural systems have been unable to cope with the loss and damage linked to negative effects of climate change (UNFCCC, 2013). In view of this, the recurrent humanitarian crises in many parts of Africa together with heightened climatic shocks resulting from climate change and increased geopolitical uncertainty are challenging the conventional wisdom regarding humanitarian assistance and calls for an alternative perspective have become more frequent in recent years (Frankenberger, Spangler, Nelson, & Langworthy, 2012; Hoddinott, 2014). Accordingly, it has been suggested that "*a focus on strengthening resilience can protect development gains and ensure people have the resources and capacities to better reduce, prevent, anticipate, absorb, and adapt to a range of shocks, stresses, risks and uncertainties*" (Bahadur *et al*., 2015a, p. 2). Hence, resilience as a concept has been rapidly evolving and is now considered as a uniting policy tool which applies to humanitarian and development approaches to resolve peoples' chronic vulnerability to recurrent shocks and stresses (Choularton, Frankenberger, Kurtz, & Nelson, 2015).

Similarly, the concept of 'resilience' has been highly popularized, be it in the Sendai Framework for Disaster Risk Reduction (UN, 2015a), the Paris Agreement on Framework Convention on Climate Change (UN, 2015b), or the Sustainable Development Goals (UN, 2015c). It is a crucial concept found in all three (Cutter, 2016). On this account, resilience is considered as a new perspective on how to investigate and design for the impacts of shocks and stress that slow down development (FSIN, 2014). Although viewed differently due to its diversified roots of origin, in the context of climate change, "resilience is the ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner" (IPCC, 2012 p. 5). Moreover, Smith *et al*. (2015) suggested that resilience is a set of capacities (i.e., absorptive, adaptive, and transformative), which help households and communities to successfully function when they face shocks and stress and still meet a set of well-being outcomes.

In Ethiopia, in general, and in Wolaita Zone, in particular, such climate change has already caused multifaceted negative livelihood impacts with different severity levels based on differences in socio-economic, demographic, cultural, and agro-ecological settings. In response to this, building the resilience capacities of smallholder farmers in a different agro-ecological setting is highly needed. IPCC in its 2014 report suggests that building resilience requires reducing exposure and sensitivity to shocks and increase adaptive capacity (IPCC, 2014). The frequency and intensity of shocks are the main reasons for paying attention and investing to enhance resilience at the individual, community, and country levels in years to come (DFID, 2011; World Bank, 2013).

The ongoing (human-induced and natural) challenges that exacerbate farmers' existing vulnerability to shocks and livelihood impoverishment at the micro-level necessitate intervention policies, strategies, and practices for these issues and should be prioritized by policymakers, academicians, and development practitioners in countries like Ethiopia. Therefore, a detailed study that links micro-meso-macro levels is required to explain the factors that contribute to farm households' vulnerability to shocks, in what contexts, at what level, and what livelihood resilience capacities exist to address such challenges in the face of the changing climate. This study thus aims to explore households' livelihood vulnerability to the changing climate and search for livelihood resilience capacities to absorb, adapt, and transform from climate change-induced shocks in Wolaita Zone, Southern Ethiopia.

1.2 Statement of the problem and rationale of the study

Ethiopia is the second-most populous country in Africa with an estimated population of over 105 million (CIA, 2018). The economy heavily depends on agriculture that contributes 40.2% of the national GDP, 70% of export earnings and at least 80% of the labor force (AfDB, 2015). However, this huge sector has been seriously challenged by climate change (Kidane, Maetz, & Dardel, 2006; NMA, 2007; Simane, Zaitchik, & Foltz, 2016) contributing to the high level of absolute poverty (23.5% in 2015/16) in the country (NPC, 2017 p.22).

Several studies have documented substantial evidence showing that climate is changing in Africa, including Ethiopia and will do so at an increasing rate in the future (Boko *et al*., 2007;Thomas, Twyman, Osbahr, & Hewitson, 2007; Cooper *et al*., 2008; Conway & Schipper, 2011; Simane, Zaitchik, & Ozdogan, 2013; Eshetu *et al*., 2014) indicating that the future is uncertain in many parts of Africa, including Ethiopia. A 2011 UNDP report stated that climate change generates various kinds of risks that would affect all sectors in Ethiopia (UNDP, 2011).

There is evidence that shows continued incidences of meteorological drought episodes resulting in human, crop and livestock losses, food insecurity and even famine to the Ethiopian population (EPCC, 2015; Savage, Mujica, Chiappe, & Ross, 2015), particularly affecting the livelihoods of smallholder farmers (Amsalu &Alebachew, 2009;Alebachew& Amsalu, 2012; Bewket, Radeny, & Mungai, 2015; Savage *et al*., 2015). Specifically, with this changing climate, the country has experienced 47 major floods since 1900, which killed close to 2000 people and affected 2.2 million (You & Ringler, 2010). Twelve extreme droughts were recorded between 1900 and 2010, which killed more than 400,000 people and affected over 54 million people (You & Ringler, 2010). In terms of occurrence, many of the droughts and floods occurred since 1980 (World Bank, 2010).This is also expected to continue as changes in temperature and perception are likely to increase the frequency of severe droughts and floods (Savage *et al*., 2015).

As a result of such climate variability and change, and the resulting shock incidences, Ethiopia is often labeled as highly vulnerable (World Bank, 2010; Conway & Schipper, 2011). It is a country which highly suffers from risks associated with high rainfall variability (EPCC, 2015) and exposed to famine (Wassie & Fekadu, 2015). In terms of specific impacts, Ethiopia ranks 46th among countries most at risk from climate risk in 2019 (Eckstein, Hutfils, Marie-Lena, & Winges, 2019 p.29). On the other hand, a study by the World Bank (2010) projects that unless strong efforts to build resilience are put in place, climate change will cut Ethiopia's GDP growth up to 10% by 2045-between 0.5 and 2.5% each year (EPA, 2011).

On these account, Ethiopia's vulnerability to climate change impacts are aggravated by high dependence on climate-sensitive sectors for livelihoods, poor infrastructure, widespread environmental degradation and fragile ecosystems, limited national scientific, technological, financial and institutional capacity (Simane, 2011; UNDP, 2011; Bishaw *et al*., 2013; Bewket *et al*., 2015; Bayrau, Bekele, Assefa, & Hagos, 2015; EPCC, 2015; Savage *et al*., 2015; Wassie & Fekadu, 2015; Simane *et al*., 2016).

In Wolaita *Zone*, the focus of this study, the impacts of climate variability and change are high and made even worse due to unfavorable coping strategies as well as poor livelihood resilience capacities of the vulnerable groups. For example, 3026 hectares of land around the Bilate river was affected during the 2016/2017 flooding which resulted in the death of 981 livestock population, and 12,126 households remain victims (WZFED, 2017). Besides, recurrent droughts have exacerbated the vulnerability of the *Zone* and thus a total of 199,782 individuals have been supported by the productive safety net program (WZFED, 2017). Moreover, many households' in the *Zone* are dependent on seasonal out-migration to nearby towns for their livelihoods (Gecho, Ayele, Lemma, & Alemu, 2014a; Gecho, 2017; Esayas, Weldegebriel, & Enaro, 2018a).

On top of this, different empirical studies have reported that large proportion of households remain in precarious food security (Gecho *et al.*,2014b; Abo & Kuma, 2015; Leza & Kuma, 2015; Tantu, Gamebo, Sheno, & Kabalo, 2017; Gazuma, 2018).These climate change coupled livelihood impacts are intensified by the high population density, severe shortage of farmland, limited urbanization, limited employment opportunities, high level of migration outflow, low-level of rural livelihood diversification, poor access to services, inadequate resource endowments, and extreme poverty (Rhamato, 2007; Jufare, 2008; Eneyew & Bekele, 2012; Gecho *et al*., 2014a, b; Wodaje, Eshetu, & Argaw, 2016; Bedeke, Vanhove, Gezahegn, Natarajan, & Van Damme, 2018; Esayas *et al*., 2018a). The recent El Niño[2]induced drought has affected an estimated 15 million people as of March 2016 across the country (FAO, 2016a; WFP, 2016) and Wolaita *Zone* is among the major food deficit and famine-prone areas (Rahmato, 1992; FEDD, 2003; Jufare, 2008, Gecho, 2017) where the most destitute and vulnerable farm households find it very hard to recover, adapt, and transom from such shocks without a strong support from concerned bodies. Despite observed and projected impacts of climate variability and change on people and livelihoods in various parts of Ethiopia, the historical trends of climate extreme events and the current experiences of such shocks in different agro-ecological settings of the study area are not well documented and require an empirical study like the one at hand.

In the face of high climate variability and change impacts, the IPCC (2012) noted that building resilience addresses individuals, households, communities, countries, and regions needs to anticipate, prepare for, cope with, and recover from shocks and stresses. Thus, to take remedial actions, comprehensive studies, and empirical evidence at the micro-level is needed to make informed decisions by the concerned bodies to the real problems.

Resilience is popular in development studies, including studies dealing with poverty, vulnerability and food security. Nevertheless, it has been a challenge to find sound measures (Alfani, Dabalen, Fisker, & Molini, 2015;Bahadur *et al.*, 2015b) to quantify resilience (Béné, Godfrey Wood, Newsham, & Davies, 2012; Alfani *et al.*, 2015; Bahadur *et al*., 2015b; Cutter, 2016). Through a recent discourse, some attempts have also been made to explore resilience from different perspectives in Ethiopia (e.g., Demeke & Tefera, 2011; Maxwell, Vaitla, Tesfay, & Abadi, 2013; Tefera & Kayitakire, 2014, 2018; Smith *et al*., 2015; Tesso, 2017; Weldegebriel & Amphune, 2017; Asfaw, Maggio, & Palma, 2018; Asmamaw, Ambelu, & Mereta, 2018). As evidenced in these studies, the use of rigorous analyses is preferred to capture the complexity and the multidimensionality of livelihood resilience capacities to climate-induced shocks. However, as resilience is governed by principles, such as context-specific, unit and scale of analysis differences, results from the above studies cannot fully clarify the context and specific realities of the study area.

Apart from this, resilience has been understood from multiple perspectives. Some researchers see it as the flip side of vulnerability and focus their attention on the measurement of vulnerability to climate variability and change using the highly popularized vulnerability index method (IPCC, 2001; Deressa, Hassan, & Ringler, 2008; Cutter, Emrich, Webb, & Morath, 2009; Mohan & Sinha, 2016; Tesso, Emana, & Ketema, 2012a; Antwi-Agyei, Dougill, Fraser, & Stringer, 2013; Tewari & Bhowmick, 2014; Simane *et al*., 2016; Dechassa, Simane, & Alamirew, 2017) while others understand the two concepts separately. Thus, they measure resilience either directly using index method or indirectly through food security as a proxy (Demeke & Tefera, 2011; Mulugeta, 2014; Mengistu, Argaw, Seid, 2015; Cochrane, 2017). In the direct resilience measurement, some empirical studies have focused on a limited dimension of resilience (time to bounce back) (Teso *et al*., 2012a; USAID, 2015).

However, with the ongoing debates and recent understandings of the resilience concept (Frankenberger, Constas, Nelson, & Starr, 2014; Bene *et al*., 2015; Lisa, Schipper, & Langston, 2015; Smith *et al*., 2015; Tanner *et al*., 2015;Jones, Samman, & Vinck, 2018),it would be problematic only to focus on one or two components of resilience or livelihood resilience. In this regard, scholars argue that resilience has three different, yet interrelated capacities (DFID, 2011; Frankerbege *et al*., 2014; Smith *et al*., 2015; Bene *et al*., 2016; Knippenberg & Hoddinott, 2016; Tefera & Kayitakire, 2018). Thus, this study rectifies the limitations of the earlier studies and explores livelihood resilience capacities from three different and interconnected perspectives over AEZs.

On the other hand, empirical evidence of vulnerability and climate variability and change are multiple and found mixed. Some studies have highly focused on the trend analysis of climate variability and change in different contexts (Bewket & Conway, 2007; Gebrehiwot, 2013; Hadgu, Tesfaye, Mamo, & Kassa, 2013; Teferi, Uhlenbrook, & Bewket, 2015; Solomon, Yihenew, Getachew, & Birhanu, 2015; Weldegebriel & Prowse, 2016). Others examined farmers' perceptions of climate variability and change (Deressa*et al*., 2011; Hadgu*et al*.,2014; Addisu, Fissha, Gediff, & Asmelash, 2016; Habtemariam, Gandorfer, Kassa, & Heissenhuber, 2016; Asrat & Simane, 2018) while perception of climate extreme trends (Mekasha, Yirga, Tesfaye, Nigatu, & Duncan, 2016**).** Shiferaw *et al.* (2014) thoroughly reviewed managing vulnerability to drought and enhancing livelihood resilience in sub-Saharan Africa, a few others assessed climate-induced risks (You & Ringler, 2010; Bayrau *et al*., 2015) addressing mainly the exposure component of vulnerability while others fully center on vulnerability to climate variability and change (Deressa *et al*., 2008; Wassie & Fekadu, 2015; Simane *et al*., 2016; Amare & Simane, 2017; Asart & Simane, 2017; Decahssa *et al*., 2017).

Most of the scientific studies and discourses on vulnerability have been determined towards contributing to the theoretical understandings or measurements at national or regional levels based on some selected indicators to each geographic area, and identifying resilience-building strategies that imply for national and regional planning (Füssel, 2007; Hinkel, 2011). Nevertheless, the local level vulnerability analysis is an essential precondition for local-level planning and identification of resilience planning and strategies, particularly to those natural resource-dependent communities who are vulnerable to the projected climate variability and changes (Fraser *et al*., 2011). Simane *et al*. (2016) pinpointed that national level vulnerability study results cannot help to address the complexity of vulnerability at the agro-ecological level.

Hence, it is imperative to estimate and map out farm households' vulnerability situations to the changing climate at different agro-ecological settings at the micro-level.

As a matter of fact, recent studies in the study area have focused on issues such as livelihood adaptation, risks, and vulnerability (Jufare, 2008), migration and urban livelihood (Esayas *et al*. 2018a), causes of household food insecurity (Eneyew & Bekele, 2012), analysis of wealth and livelihood capitals (Eneyew & Bekele, 2013), rural household livelihood strategies (Gecho *et al*., 2014a; Gecho, 2017), households food security/insecurity determinants (Abo & Kuma, 2015; Leza & Kuma, 2015; Cochrane, 2017; Tantu *et al*., 2017; Gazuma, 2018), and adaptation strategies to climate change (Wodaje *et al*., 2016; Wodaje, 2017; Bedeke *et al*., 2018).

There have been studies that discussed climate change impacts, vulnerability, adaptation strategies and disaster resilience in the Ethiopian context in fragmented ways. However, studies that explicitly explore and link vulnerability to the changing climate and investigate livelihood resilience capacities (absorptive, adaptive, and transformative) to climate variability and change-induced shocks from agroecological perspective by integrating theories of vulnerability and livelihood resilience using rigorous methodological approaches to capture the issues holistically at the micro-level are scanty. This reality is among the major reasons necessitated this study.

More importantly, regardless of the sustained households' vulnerability to shocks, recurrent droughts, high food insecurity and poverty, livelihood impoverishments, limited resources endowments, fragmented and infertile land, agricultural productivity and market linkage problems, population pressure on agricultural land, limited access to productive assets among others have been influential to increasing vulnerability to shocks and remain serious bottlenecks for resilience-building strategies. Nevertheless, from the reviews so far, comprehensive empirical studies examining farmers' livelihood vulnerability conditions while exploring livelihood resilience capacities from agroecological perspectives in the face of climate variability and change have not been sufficiently conducted or nonexistence in the study area, suggesting critical research gaps that calls for a focused study like the one at hand. Therefore, conducting such empirical research holistically is very timely and relevant to document the local level experiences for development interventions by different actors as well as sharing practical knowledge to the academic community at different geographies of scale, primarily because livelihood resilience is one of the emerging research agenda in development studies.

1.3 Objectives of the study

1.3.1 General objective

The main objective of the study is to explore farm households' livelihoodvulnerability situations to the changing climate and investigate resilience capacities from absorptive, adaptive and transformative perspectives in Wolaita *Zone*, Southern Ethiopia.

1.3.2 Specific objectives

i). To investigate the trends in extreme climate events in three agro-ecological *Zone*s(Paper-I);

ii). To characterize climate trends and determine farmers' climate change perceptions in three agro-ecological *Zone*s (Paper-II);

iii). To assess farmers' livelihood vulnerability conditions to climate variability and change in three agro-ecological *Zone*s (Paper-III);

iv). To measure livelihood resilience capacitiesto climate shocks and the determinants of households' level of resilience (Paper-IV).

1.4 Basic research questions

1. What are the historical trends of extreme climate events in each agro-ecological *Zone*?
2. What trends and patterns have been observed in the temperature and rainfall data in the agro-ecological *Zone*s? How do farmers perceive climate variability and change, and associated shocks and what correlations exist between the historic climate trends and farmers' climate perceptions?
3. How vulnerable is the farmers' livelihood situations in each agro-ecological *Zone*to the changing climate? Is there any difference in vulnerabilitycondition between and among agro-ecological *Zone*s?
4. What is the livelihood resilience capacity of farm households to the observed climate shocks? What factors determine the households' level of resilience?

1.5Delimitation and limitations of the study

Though environment and development as a field of study involvemany research themes, this study was concerned with households' livelihood vulnerability conditions to the changing climate and explore livelihood resilience capacities from absorptive, adaptive, and transformative perspectives focusing on three agro-ecological settings in Wolaita, Southern Ethiopia. In spite of the debates on the unit of measurement vis-à-vis livelihood resilience, including individual households, community, and/or system levels, review of the recent empirical studies at different geographies of scale suggests that the main unit of analysis is the household. Programs that encourage resilience at the community and higher systems levels increasingly measure livelihood resilience at the household level. Moreover, since one of its principles is to find out the level analysis for a proper quantification, the household, in this study, forms the unit of analysis.

Even though different forms of classifications have been used to categorizeEthiopia's climatic system, agro-climatic *Zones*(ACZ) and traditional agro-ecological *Zones*(AEZ)[3](Table 1.1) are the two most commonly used classification systems (Deressa *et al.*,2010). Accordingly, Wolaita *Zone* is subdivided into three traditional agro-ecological *Zone*s, namely, the midland (*Weynadega*, 56%), lowland (*Kolla*, 35%), and high-land (*Dega*, 9%) (Gecho *et al*., 2014a). The focus on agro-ecological view is mainly because of the increasing role of agro-ecology. Thus, it is rapidly growing as a scientific discipline, a sustainable farming approach, and social movement (Silici, 2014). Moreover, with the changing climate and its adverse effects on peoples' livelihoods, some attempts have been made to promote "*agro-ecology as the sustainable alternative to the climate changecrisis*" (Thapa, 2015 p. 40). In view of this, the study area AEZs mostly fit into the traditional AEZs classified under highland, midland and lowland (Deressa*et al*., 2010; Gecho *et al*., 2014a), Therefore, this study applied the traditional AEZ classification approach.Three *Weredas* (i.e., one high-land, one midland, and one lowland), representing the three AEZs, were selected to represent the study area and fit the study objectives.

Although the study analyzed climate variability and change, livelihood vulnerability, and livelihood resilience capacities in three AEZs of Wolaita Southern Ethiopia holistically, it had limitations. Some of the major limitations include, the use of the three available meteorological stations (one station in each AEZ)from the gridded dataset for comparison purposes and the climate variability analysis merely emphasizing on the annual time scale, which could have better explained the trends of seasonal climate variability and change using the average of all grid points over AEZs. Even if data on food security metrics were collected, owing to a chapter based analysis, it was not included in any of the Ph.D. chapters that otherwise would have highlighted the factors contributing for farm households' food security or insecurity situations in the study area. Retrieving secondary data, particularly, the disaster dataset of Ethiopia was very much challenged and it took a longer time, which added the time load on the data analysis.

Given the survey data was collected in the aftermath of the recent 2015/2016 El Niño-induced severe drought, thus total crop production information and annual cash income earned from the sales of crop and livestock was partly impacted by the shock. In this study, the livelihood resilience capacities are explored from, absorptive, adaptive, and transformative perspective to have a broader picture of the livelihood in the face of climate variability and change. However, detailed discussions of the sustainable livelihood framework, including the policies, processes and laws and other components that cannot fall under the recent resilience thinking are beyond the scope of the study. Finally, the study did not have an adequate budget and mostly self-financed, which coupled with my critical health problem has needed extra time as opposed to the planned date of completing the Ph.D.

1.6Conceptual framework of the study

Even though number of frameworks[4]have been developed in relation to resilience to various types of shocks[5]or stress[6],including climate-induced shocks or in different geographies of scales,the disaster resilience framework developed by the UK Department for International Development (DFID, 2011) has been widely considered as the foremost attempt to document the four major elements of resilience[7]: context, disturbance, capacity to deal with disturbance, and reaction to disturbance (DFID, 2011). Other methods include, Department for International Development (DIFD) and TANGO's consultant resilience framework (Smith *et al*., 2015), Livelihoods Change Over Time (LCOT) model by Tuft University (Maxwell *et al*., 2013) and Community Based Resilience Analysis (CoBRA) framework (UNDP, 2014), among others while Alinovi, Mane, and Romano(2010) added improved livelihoods as elements of resilience.

Moreover, several resilience frameworks have so far been developed (see also Brooks, Aure, & Whiteside, 2014), though, many of them are fragmented with a focus only on a certain aspect. The resilience assessment framework developed by Frankenberger *et al*. (2012), on theother hand, attempts to address the drawbacks of the previous studies and integrates issues such as livelihoods, disaster risk reduction, and climate change adaptation approaches into a single framework for assessing resilience. Similarly, the conceptual framework of this study relies on three different perspectives, 1)the three dimensional (*3-D resilience framework, 2)* sustainable livelihood framework (SLF), and 3) vulnerability framework to investigate the objectives of the study holistically. On the other hand, since resilience has many components, it is imperative to clearly set out the components studied. Accordingly, this study[8]was based on the recent work of Cutter (2016), in which he suggested that resilience study should identify *resilience to what*, and *resilience for whom*.

The study adapted the 3-D resilience framework, which recommends that resilience arises as a result of three capacities: absorptive, adaptive and transformative capacities (Béné *et al*., 2012; Béné, Headey, Haddad, & von Grebmer, 2016) to capture the multidimensionality of livelihood resilience in the face of climate variability and change over drought-prone and vulnerable AEZs in Wolaita, Southern Ethiopia. Béné *et al*. (2016) also observed that each capacity results in a different outcome: persistence, incremental adjustment, or transformational responses, which will be instrumental for planning and implementing policies and strategies that address the gaps in each of the resilience capacity that fit the local level realities. The study also included the perspectives of DFID (2011) and Frankenberger *et al*. (2012) along with other components of the conceptual framework in order to capture the objectives of the study holistically. In other words, the following conceptual framework was primarily designed to guide the research work and which show the complex and multiple webs of interactions between and among the major components and/or objectives of the study.

In this regard, vulnerability context as a component of SLF (DFID, 1999; Rakodi, 2002) was considered as one of the major components of the frameworkand was used to investigate climate-induced shock/extreme climate events (*e.g.,* floods, droughts, crop failure, crop pest and disease, livestock disease, and human disease) in the study area context. The study also looked into the current situations of shocks in the study areaand their trendswhich helpedin the computation of household's livelihood vulnerability index (LVI) for the three different agro-ecological settings. In the SLF, vulnerability context is viewed as the degree of exposure and susceptibility to risks, its sources are embedded on *trends* (economic, population, resources stock, technology, and governance); *shocks* (drought, flooding, diseases and illness); and *seasonality* (prices, health, employment, production) (Chambers & Conway, 1992; Ellis, 2000; Rakodi, 2002). Context in the livelihood resilience framework was applied to indicate the system or process, and the resilience being measured, which is often called 'resilience of what?' It includes social groups, communities, households, countries, institutions, regions and ecosystem among others (Brooks *et al*., 2014).

The vulnerability context (in this study, climate-induced shocks or trends of shocks/extreme climate events) can adversely affect or aggravate households' vulnerability conditionsas viewed from exposure, sensitivity,and adaptive capacity perspectives. As shown in the framework, the higher the vulnerability context of a household, the higher household's exposure and sensitivity situations with limited adaptive capacity would be. On the contrary, when household's exposure to shocks and sensitivity is lower with higher adaptive capacity, the vulnerability context would be lower and the effect remains minimal. Furthermore, vulnerability context can also affect and be affected by those factors which are assumed to influence both livelihood vulnerability and livelihood resilience capacities of households to climate-induced shocks and to the changing climate either positively or negatively.

The other component of the framework, vulnerability, is based on the conceptual framework of IPCC (2007 &2014) and is understood in the study as a function of exposure, sensitivity and adaptive capacity. As depicted in the framework, it has both forward and backward linkages with factors affecting both livelihood vulnerability and livelihood resilience capacities, on one hand, and livelihood resilience capacities (i.e., absorptive, adaptive, and transformative), on the other hand (Figure 1.1). It also has a cause and effect interplay between the vulnerability context of households and households' livelihood vulnerability to the changing climate. In this case, these components are primarily important in developing both the livelihood vulnerability index (LVI) and IPCC-LVI (Chapter 4).

Since the framework was developed based on the conceptual understandings, theoretical foundations and empirical studies of various constructs such asvulnerability context, vulnerability, and livelihood resilience capacities, it interacts with the major components of the framework dynamically. Furthermore, the determining factors included in the conceptual framework were in line with those variables included in the econometric models pertaining to the study objectives framed along demographic, socio-economic, ecological, livelihood assets (i.e., human, social, physical, financial, and natural). These factors or determinants have a cause and effect interactions with vulnerability context and households' vulnerabilityon the left side of the framework and households' livelihood resilience capacities (e.g., absorptive, adaptive, and transformative) on the right side. Therefore, the determinants were at the center of framework and were important in constructing an econometric model, including, OLS, binary logit model, quantile regression and households' livelihood resilience capacity indices using indicator-based approach (Asmamaw*et al*., 2018), in general, and develop both the livelihood vulnerability index (LVI) and IPCC-LVI of households in each AEZ(Etwire, Al-Hassan, Kuwornu, & Osei-Owusu, 2013; Tewari & Bhowmick, 2014; Simane *et al*., 2016; Dechassa *et al*., 2017; Asrat & Simane, 2017; Adu, Kuwornu, Anim-Somuah, & Sasaki, 2018; Amuzu, Kabo-Bah, Jallow, & Yaffa, 2018; Tessema & Simane, 2019), in particular.

Lastly, the conceptual framework adapted the contemporary understanding of livelihood resilience that involves three interrelated capacities (e.g., absorptive, adaptive, and transformative) (Béné, Frankenberger, & Nelson, 2015; Bahadur *et al*.,2015a,b; FAO, 2015; Smith *et al*., 2015; Weldegebriel& Amphune, 2017; Asmamaw*et al*., 2018; Tefera & Kayitakire, 2018). This recent perspective of livelihoodresilience is vital to help determine the extent to which households, communities and higher-level systems (e.g., national, regional, global) are on a trajectory toward greater vulnerability or greater resilience (DFID, 2011; Frankenberger *et al*., 2012). Since one of the study objectives was to explore households' livelihood resilience capacities from absorptive, adaptive and transformative perspectives to the changing climate and its adverse impacts, it was an important component in constructing the livelihood resilience capacities indices and, thereby developed econometric models-OLS and quantile regression to figure out what factors contributed to households' differential levels of resilience. As indicated in the framework, the contemporary understanding of livelihood resilience plays acrucial role both to mitigate or minimize the adverse impacts climate-induced shocks and estimate households' livelihood vulnerability to the changing climate.

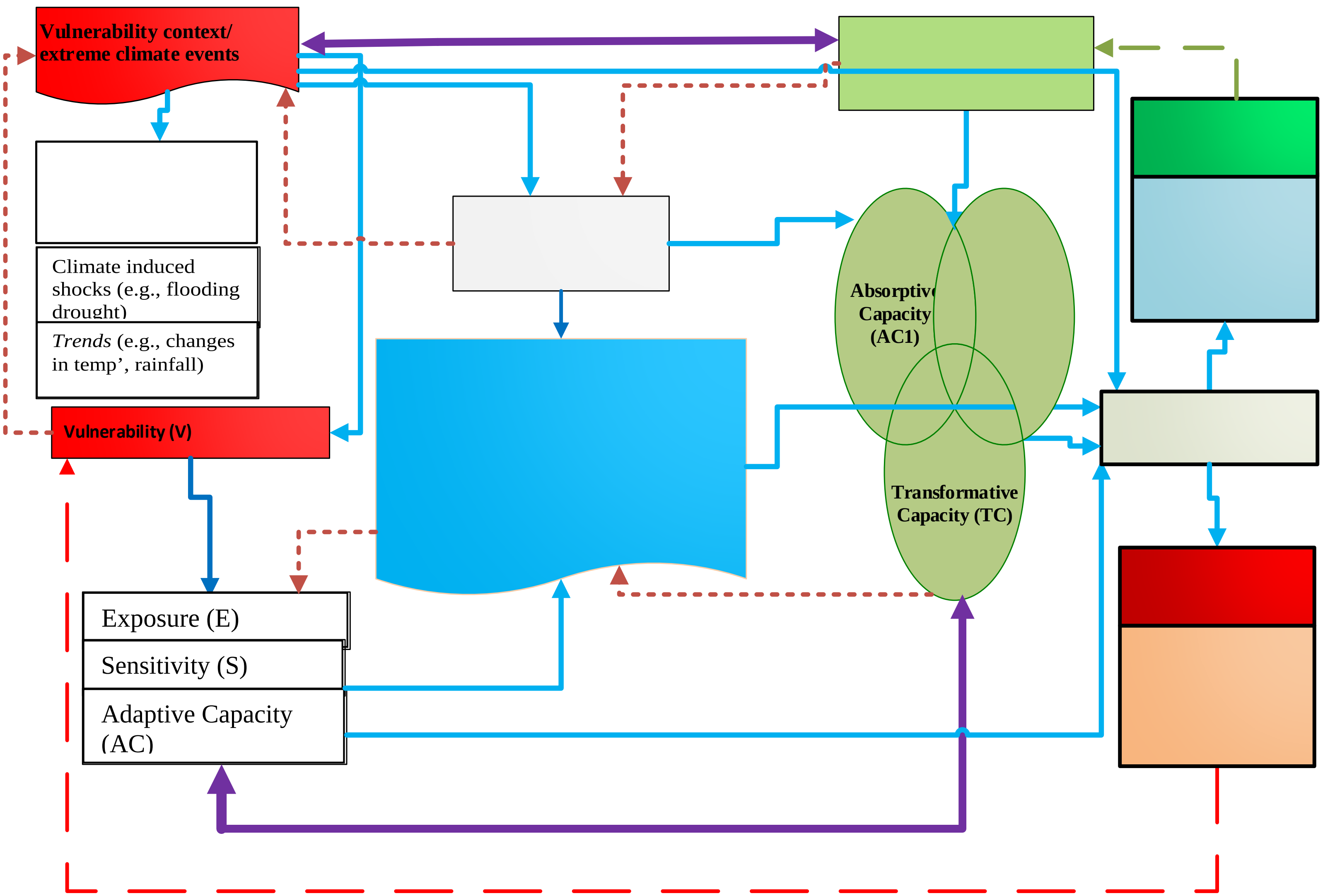

Figure 1.1 Conceptual framework of the study

Source: Own construction based on Rakodi (2002); DFID (2011); Frankenberger *et al*. (2012); IPCC (2007 &2014)

The central argument of this Ph.D. dissertation was to validate that farm households'livelihood vulnerability to the changing climate is context-specific, that there exist differences from inter and intra households' perspectives, and that disparities are common within the designated geographic settings/agro-ecological *Zone*s. Therefore, the study first explored the types of livelihood resilience capacities and then established the contribution of absorptive, adaptive, and transformative capacities towards households' livelihood resilience to the rapidly changing climate at the local level, linking such with the meso and macro level realities. With such a perspective, the study is different from previous studies wherein vulnerability was seen as the "flip side to resilience" (IPCC, 2001).

As illustrated in Figure 1.1, cause andeffect interplays, forward and backward linkages, and the multiple interactions among the components of the framework result in what Frankenberger*et al*. (2012) called vulnerability pathway (e.g., food insecurity, malnutrition, and environmental degradation) or resilience pathway (e.g., food security, adequate nutrition and environmental security) and what Tolossa (2005) in SLF calls desirable or undesirable outcomes. In view of this, it was anticipated that the complex web of interactions among the components of the framework keep households either in vulnerability pathway or the resilience pathway (Chapter 5). In the former case, households havelimited livelihood resilience capacities, remain highly vulnerable to shocks, and the shocks remain persistent which in turn forces the farm households to fall back to the vulnerability trajectory (Chapter 5). While in the later case, households would continue through the resilience pathway with positive outcomes such asreduced number of shocks, enhanced livelihood resilience capacities, and possiblelow vulnerability levels. In other words, the positive outcomeswould help farm households to keep in the resilience trajectory while adverse effects of climate change persist or continue.

In general, the framework was designed to capture the multidimensionality of both livelihood vulnerability and livelihood resilience concepts, the complexity of their measurements. It also aimed to investigating what factors really affect households' livelihood vulnerability situations to the changing climate and livelihood resilience capacities to adverse effects based on a combination of both cross-sectional and time-series data at the local level. The framework helped to scrutinize how climate-induced shocks affected livelihood outcomes or household well-being at different agro-ecological settings, and the importance of access to productive and livelihood assets inenabling households toabsorb, adapt and transform (e.g., *build livelihood resilience*) in response to shocks and climate-related changes.

1.7General description of the study area

1.7.1 Biophysical settings

The study was conducted inWolaita *Zone*, which is located in Southern Nations and Nationalities People (SNNP) region, 390 kmin the Southwest ofAddis Ababa. The newly constructed asphalt road that passes through Hosanna to Arba Minch has reduced the distance from the capital to 330 km. The absolute location of the *Zone*isroughly between 6.4°-7.1° N latitude and 37.4°-38.2° E longitude (Figure 1.2). In terms of relative location, Wolaita *Zone* shares boundary areas with Kambata Tambaro *Zone* in the North, Sidama *Zone* in the East, the former Gamo Gofa *Zone* in South, and Dawro *Zone* in the West (Figure 1.2). Administratively, Wolaita *Zone* is sub-divided into twelve *Weredas*[9]and three registered towns and/or town Administrations.

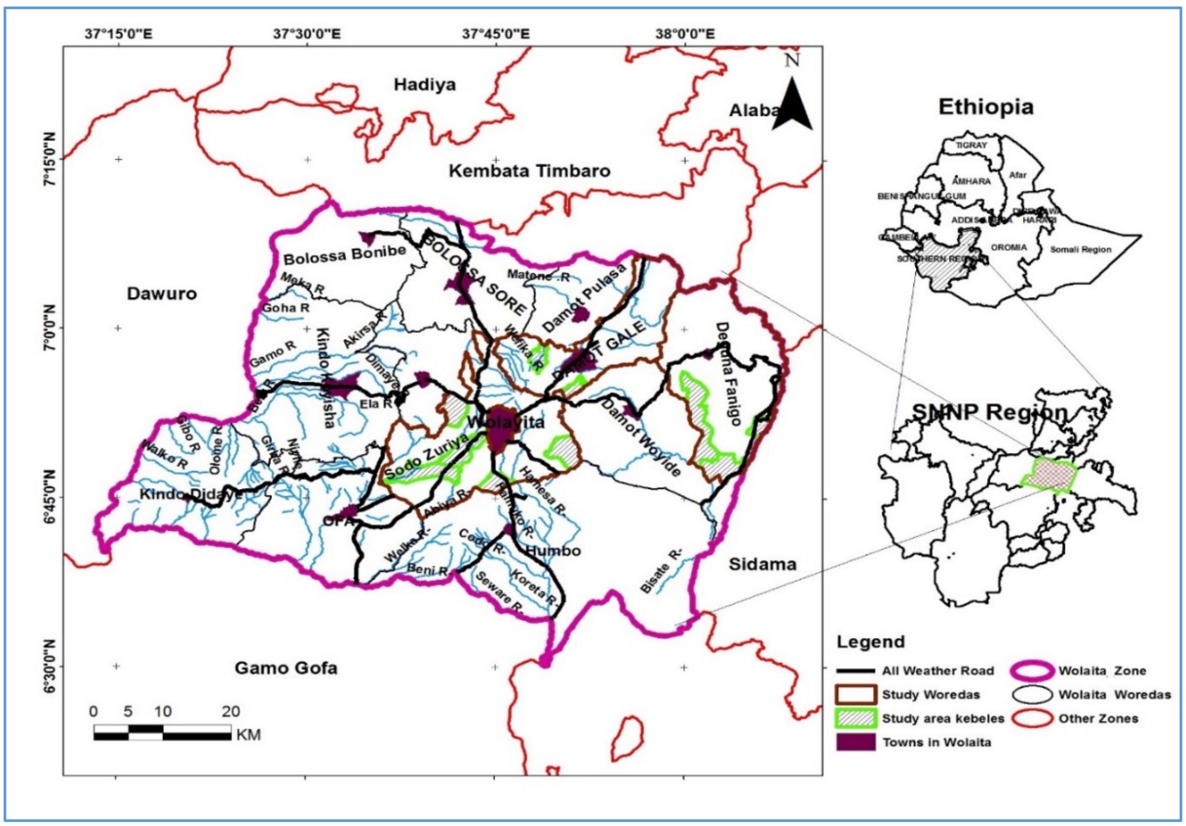

Figure 1.2Location of the study area

Relief: The study was carried out in three selected *Woreads* and 11 *Kebele*s representing three AEZs, namely Damote Gale (highland), Sodo Zuria (midland), and Duguna Fango (lowland) (Figure 1.2 and Figure 1.4).It covers a total area of 451,170 hectares or 4511.7 /km^2. The area generally has a highland relief that covers most parts of the midland while the peripheries are lowland areas (Figure 1.3). The altitude ranges from 648 meters in the lowlands at Bilate Tena to 2962 meters above sea level in the highlands of Damota Mountain (Gecho *et al*., 2014a; Gecho, 2017; WZFED, 2017).

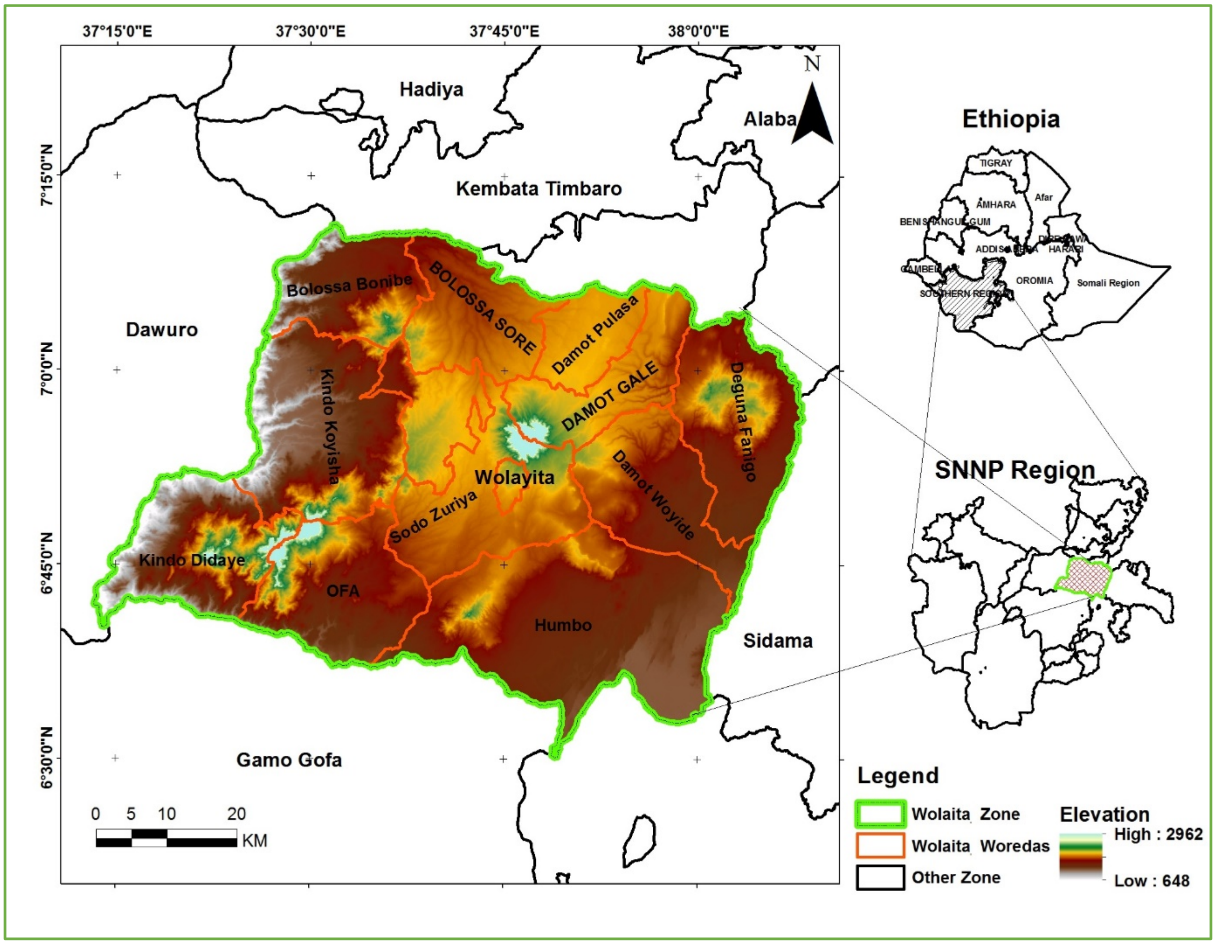

Figure 1.3Relief of the study area/AEZs

Drainage: Wolaita *Zone* is endowed with abundant water resources except in Duguna Fango, Humbo and some parts of Damote Woyde *Woreads*. The nature and orientation of the relief features resulted in the formation of some drainage systems in the *Zone*namely, Bilate Manesa, Deme, Hamasa, Woybo, Charake, Omo, Bisare. Lake Abaya is a major destination for some drainage systems. The major rivers such as, Charake, Bilate, Bisare, and other small tributaries flow into Lake Abaya (Figure 1.4) (WZFED, 2017).

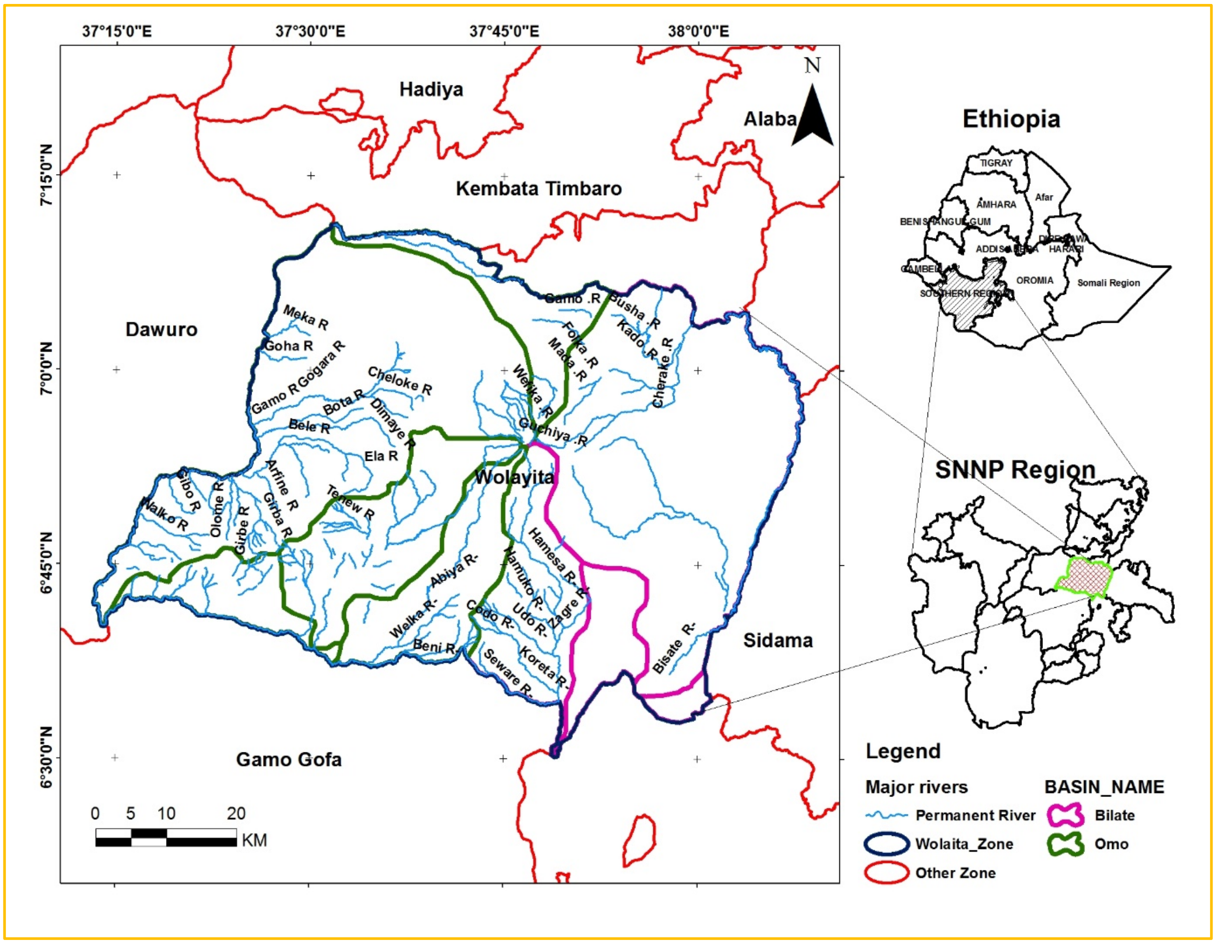

Figure 1.4Drainage of the study area/AEZs

Climate: The climate characteristics of the AEZs are shown in Figure 1.5 to Figure 1.7. The annual mean maximum temperatures (ATmax) were 27.87°C (CV=1.62 %), 26.59 °C (CV=1.35%), and 25.50 °C (CV=2.59%) for lowland, midland, and highland AEZs between 1983 and 2014, respectively. Concerning the lowest and highest observed ATmax, 2012 was the hottest year across all AEZs while 1989 was the lowest ATmax year for the midland and lowland AEZs over the last 32 years (Figure 1.5). The trend analysis exhibited an upward trend of 0.02 °C/year ($p<0.01$), signifying 0.64 °C increase between 1983 and 2014 in the lowland AEZ. The highland AEZ experienced significantly increased temperature in the ATmaxbetween 1983 and 2014. The highland AEZ experienced 1.28 °C change ($p<0.001$) paralleled with the lowland

AEZ that revealed 0.64°C increase ($p<0.01$), which shows a highly rapid rate of change in the ATmax over three decades.

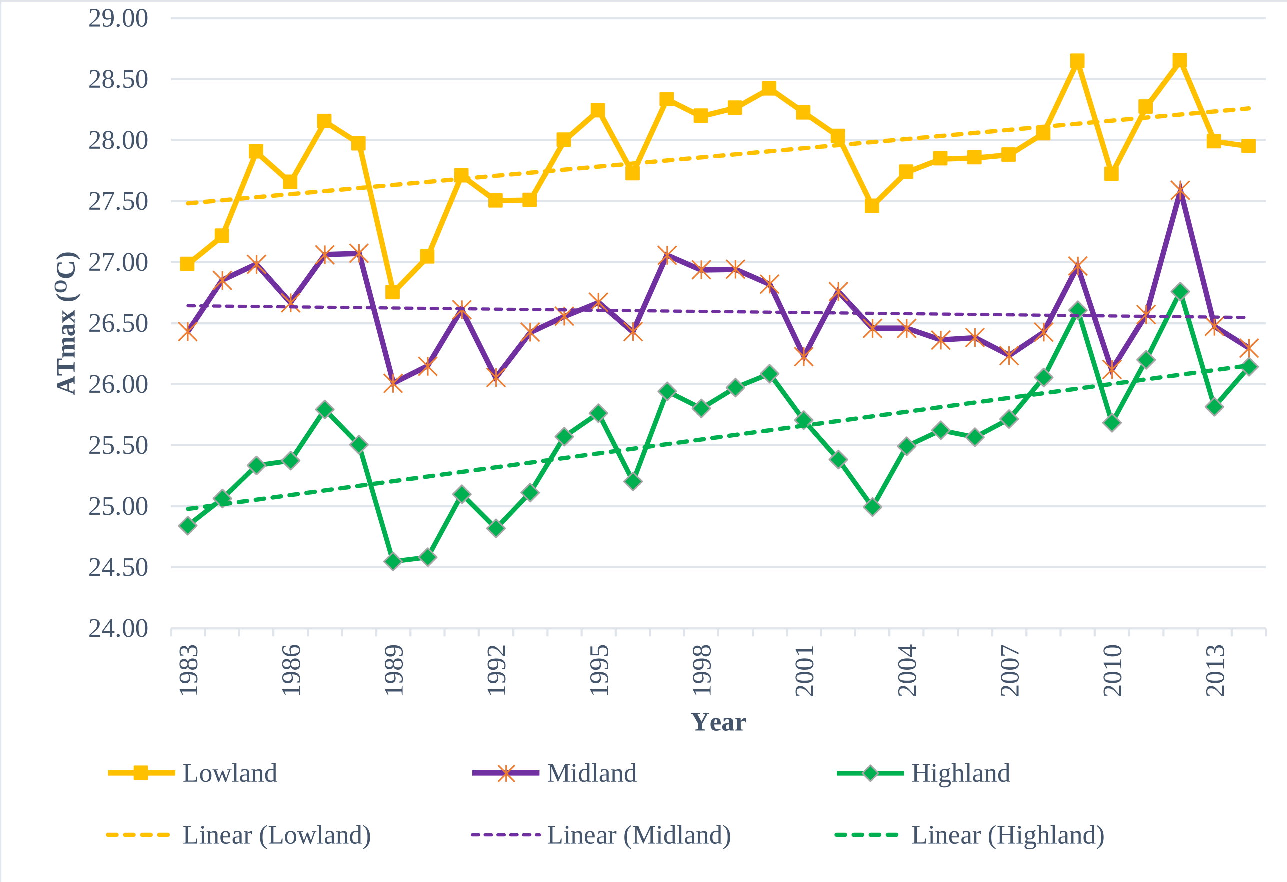

Figure 1.5Annual maximum temperature trend by AEZ

The annual mean minimum temperature (ATmin) was 14.80 °C (CV=6.49 %), 14.86 °C (CV=5.10%), and 13.64 °C (CV=7.26 %) for lowland, midland, and highland AEZs between 1983 and 2014, respectively (Figure 1.6). The ATmin shows a relativelyhigher variability in the highland AEZ than the other AEZs between 1983 and 2014. The year 1986 was the coldest year in all AEZs. The ATmin trend reveals that the same patterns were observed both for lowland and midland AEZs (Figure 1.6). It accounts for 0.05 °C/year, suggesting 1.6 °C increase in the ATmin in lowland and midland AEZs ($p<0.001$) and ($p<0.01$)over the last 32 years, respectively. The result for highland AEZ was 0.07°C/year ($p<0.001$), suggesting a highly warming trend observed in highland AEZ compared to other AEZs during the last 32 years (Figure 1.6).

Rainfall and temperature are the two most significant and sensitive climatic elements in tropical regions. The temporal and spatial distributions of trends in the annual average rainfall for the three AEZs of Wolaita *Zone* are shown in Figure 1.7. Rainfall is unpredictable by nature and variable, occurring in two different seasons. The pattern of rainfall distribution is bimodal. The main rainy season (*Kirmet*) begins in mid-June and extends to the end of September. Whereas, the short rainy season (*Belg*) extends from end of February to early April (Gecho *et al*., 2014a).

Figure 1.6Annual minimum temperature trend by AEZ

The annual total rainfall in the study AEZs varies from 697 mm in the lowland AEZ to 1181 mm in the midland AEZ (Figure 1.7). The CV also ranges from 18.57% in the highland AEZ to 25% in the lowland AEZ, suggesting a high rainfall variability on annual scale in the lowland AEZ while similar patterns have been observed both in the midland and highland AEZs. The highest annual rainfall was 1064 mm (1987), 1474 mm (2006), and 1252 mm (2007) in the lowland, midland, and highland AEZ, respectively (Figure 1.7).

On the other hand, the lowest annualrainfall was 435 mm (1999), 605 mm (1984), and 555 mm (2009) in the lowland, midland, and highland AEZ, respectively. The observed highest and lowest annual rainfall years suggest the variations in the wet and dry years among agro-ecological *Zone*s. In general, though not statistically significant, a decreasing trend was observed (1.80 mm/year) and (0.11 mm/year) in the lowland and highland AEZ, respectively while an increasing trend (10 mm/year) ($p<0.05$) was exhibited in the midland AEZ over the last 32 years (Figure 1.7).

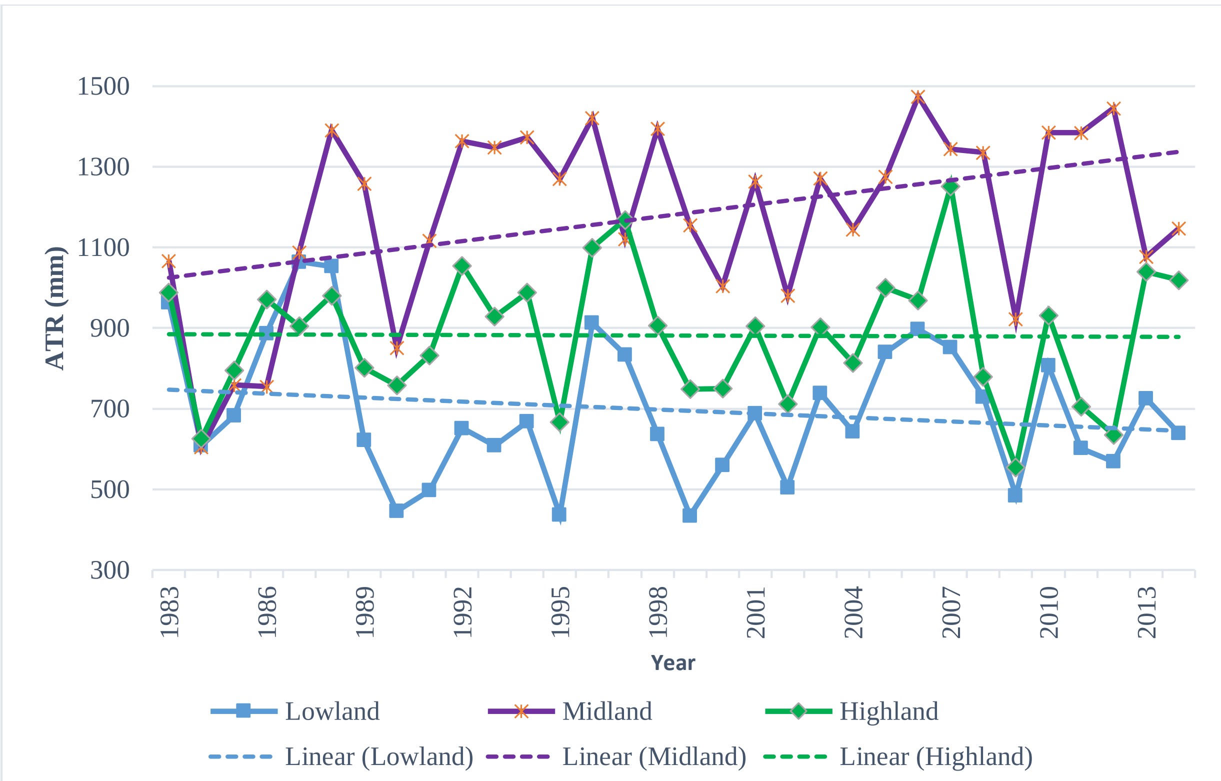

Figure 1.7Annual total rainfall trends by AEZ

Following Hurni's (1998) classification of agro-ecological *Zone*s of Ethiopia, *Kolla* agro-ecology (lowland) is characterized by relatively hotter and drier climate, whereas *Woyna-Dega*(middle land), and *Dega* agro-ecology (highland) are wetter and cooler. Using this classification, the study area is subdivided into three traditional AEZs:56 % (252655.2 hectares) of the area is a Midland (*Woyna-Dega)*; 35 % (157909.5 hectares) of the area is Lowland (*Kola)*; and the rest 9 % (40605.3 hectares) of the area is covered by Highland (*Dega)* (Gecho *et al*., 2014a; WZFED, 2017) (Table 1.1).

Table 1.1 Traditional agro-ecological zones and their physical features

AEZs	Altitude (meters)	Rainfall (mm/year)	Growing period length (days)	Mean annual temperature (ºC)
Upper highland (Wurch)	Above 3200	900-2200	211 - 365	< 11.5
*H*ighland (*Dega)*	2,300-3,200	900-1,200	121 - 210	17.5/16-11.5
Midland (Weyna-Dega)	1,500-2,300	800-1,200	91 - 120	17.5/16-11.5
Lowlands (Kola)	500-1,500	200-800	46 - 90	27.5-20
Desert (Berha)	below 500	below 200	0 - 45	>27.5

From the existing few stations, using the latitude and longitude, three main stations were selected to compare and represent the study AEZs, namely Bilate (lowland), Wolaita (midland), and Boditi (highland) (Figure 1.8 and Table 1.2). The varied agro-climatic conditions are the bases for agro-ecology based comparative analysis vis-à-vis the study objectives. In other words, after Hurni (1998) and MoA (2000), this study adopted the traditional AEZ grouping approach to compare and represent highland, midland, and lowland AEZ, respectively (Figure 1.8).

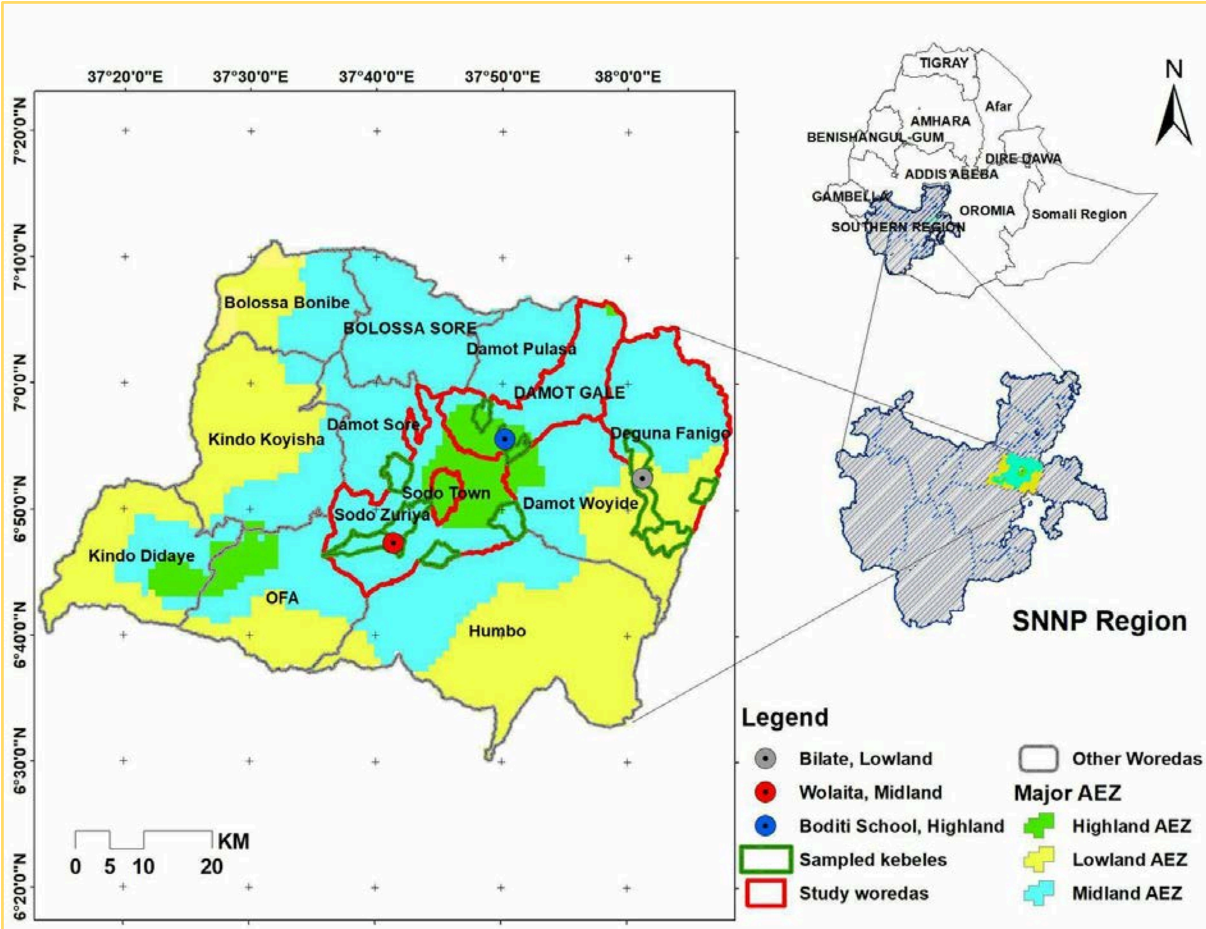

Figure 1.8Location of the study agro-ecological *Zone*s and meteorological stations

Table 1.2Selected meteorological station in Wolaita Zone

No.	Station name	Lon.	Lat.	Altitude(m)	AEZs	Duration
1.	Boditi School	37.96	6.95	2043	Highland	1983-2014
2.	Wolaita	37.58	6.81	1854	Midland	1983-2014
3.	Bilate	38.08	6.81	1361	Lowland	1983-2014

1.7.2 Socio-economic settings

Based on the 2013 population projection by the Central Statistical Agency of Ethiopia (CSA), Wolaita *Zone* had a total population of 1,808, 548. Out of this, 920, 300 (50.88%) were females and 888, 248 (49.11 %) were males.The vast majority of the *Zone*'s population (82.24%) resides in rural areas (Figure 1.9), suggesting a very limited level of urbanization.

In terms of population density[10], Wolaita *Zone* is one of the most densely populated areas in Ethiopia (Rhamato, 2007). The total size of population of the *Zone* is 1,808,548 while the total area of the *Zone* is 451170 hectares or 4511.7 km^2. Hence, the crude population density of the *Zone* is 400.85km^2 people per square km (CSA, 2013).

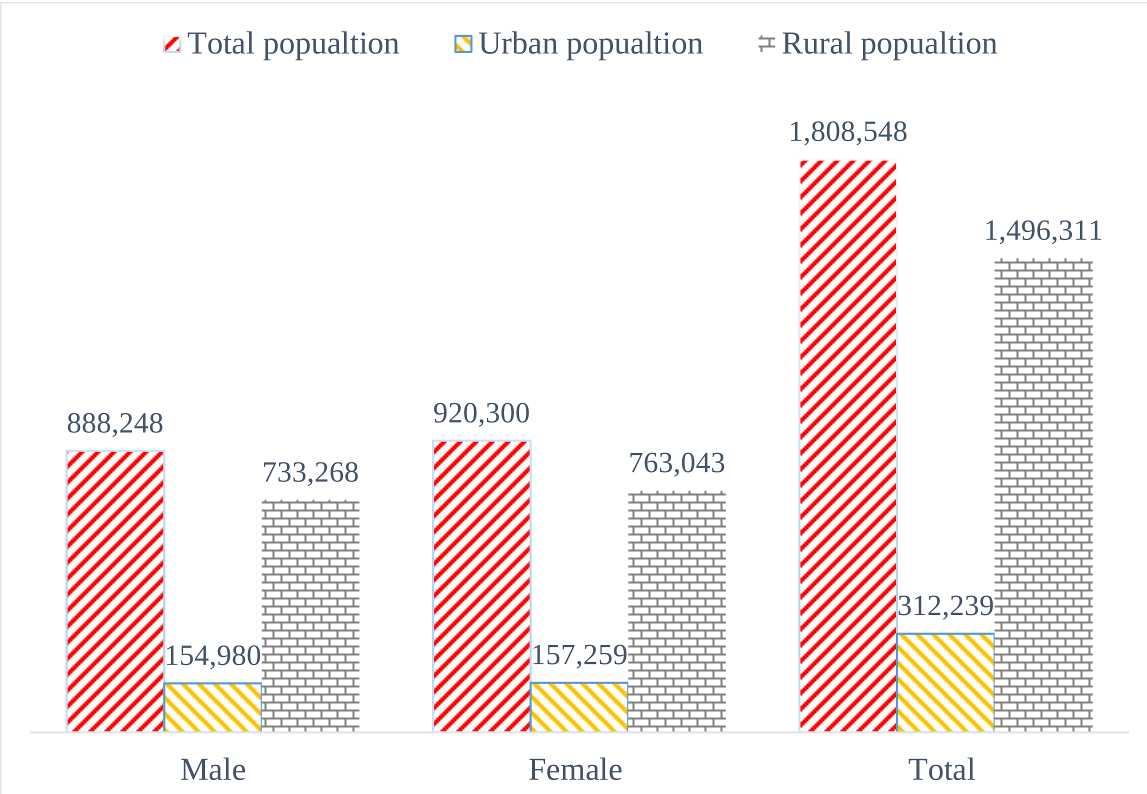

Figure 1.9Population of the study area

There is notable variation in population density from *Wereda to Wereda*. The most densely populated *Wereda* in the *Zone* is Damot Pulasa *Wereda* with 825 people per square km and the least populated *Wereda*is Humbo with 189 people per square km (WZFED, 2017). The population of the study area is characterized by a young age structure with a rapid population growth (2.9 % per year). The population of children under age 15 is 940,352 (47.8%) and the proportion of the working-age population at the age group of 15-64 years is 987,617(50. 2%).The proportion of populations aged 65 and above is 38,319 (1.9%) (Table 1.3), suggesting an average of 99.1 % dependency ratio (WZFED, 2017). The highest dependency ratio is found in the lowland AEZ while the ratio is smallest in the midland AEZ (Table 1.3).

Table 1.3 Dependency ratio of the study area by AEZ

AEZ	Area	0-14	%*	15-64	%*	65^+	%*	0-14 and 65^+	%*	Total population	Density km2	Dependency ratio
Highland	*236*	80,226	49.4	78,608	48.4	3,365	2.1	83,591	51.49%	162,337	689	106.3
Midland	*348*	100,923	48.3	103,050	49.4	4,800	2.3	105,723	50.64%	208,773	600	102.6
Lowland	*402*	66,076	53.1	56,045	45.1	2,236	1.8	68,311	54.93%	124,357	310	121.9
Total	*4,512*	940,352	47.8	987,617	50.2	38,319	1.9	978,671	49.77%	1,966,404	436	99.1

*Percent from total population

With regard to the social service, the total student-teacher ratio for grades 1-4 is 87, 44 for grade 5-8, 36.8 for grade 9-10, and 31 for grade 11-12. For the AEZs, the lowland has the lowest and the midland the highest student to teacher ratios (Table 1.4), which has implications for transformative resilience capacities in the three AEZs.

Table 1.4Primary and secondary school student-teacher ratio by AEZ

AEZ	Grade 1-4			Grade 5-8			Grade 9-10			Grade 11-12		
	Student	Teacher	Ratio	Student	Teacher	Ratio	Student	Teacher	Ratio	Student	Teacher	Ratio
Highland	27062	305	89	13098	300	44	2596	107	24	744	19	39
Midland	26447	266	99	14585	291	50	3252	104	31	172	5	34
Lowland	19075	238	80	9866	234	42	6160	111	55	1743	19	91
Total	319109	3663	87	167781	3775	44	64675	1756	36.8	19104	612	31

The per capita service utilization was 64 in the study area while it is 61 for midland AEZ and 43.3 in the highland AEZ (Table 1.5), suggesting a slight disparity between the highland and the other AEZs.

Table 1.5All health service utilization rate by AEZ

AEZ	Population	Total health service utilization	All visits per capita
Highland	156,234	67,712	43.3
Midland	119,438	72,830	61.0
Lowland	172,632	103,648	60.0
Total	188,2829	1,204,500	64.0

The agricultural extension service coverage in the study area stands at78 %. The smallest agricultural extension coverage (29%) was in the lowland AEZ whereas the largest was in the highland AEZ (79%) (Table 1.6). Thus, it is possible to infer that there is a clear disparity among AEZs on the extension services coverage.

Table 1.6Farmers household extension workers 'ratio by AEZ

AEZ	Household size	Extension worker	Ratio	Beneficiaries from extension program	Coverage
Highland	29,868	120	242	23109	79
Midland	39,140	86	455	25640	66
Lowland	23,638	54	438	6709	29
Total	361,081	1002	360	259811	78

In terms of livelihood activities, farm households practice mixed farming involving the production of cereals, root crops, *Enset*, and coffee. Regarding *Enset*, Wolaita is part of what is known as the *Enset* farming system (often called *enset* complex or *enset* culture) (Rhamato, 2007).*Enset* is an essential crop that serves as one of the staple foods the study area. This is due to the fact that the study area context is characterized by severe scarcity of land and cereal harvests are low. Thus, high yielding *Enset* provides some form of food security. *Enset*is also popular due to its drought-resistant properties (Rhamato, 2007; Jufare, 2008).

According to Eneyew and Bekele (2013), Wolaita *Zone* is primarily subdivided into two livelihood *Zone*s namely, ginger and coffee, on one hand, and maize and root crops, on the other. The latter covers most of the midland and upper lowland or dry midland terrains of Wolaita *Zone* (Figure 1.8). On the other hand, crop production is the main means of livelihood while livestock serves as a source of food, cash income and insurance against uncertainty. In the highland, cereals, root crops and perennials widely grow (Jufare, 2008).

As shown in Figure 1.10, the amount of crops produced, on average, has shown increasing trends between 2003/2004 and 2017/2018 production years. The production of Teff, Haricot Bean, and Sweat Potato dominate and show increasing trends over the last 15 years while Cotton, Sesame, and Chick Pea are very much limited in the total amount produced in the same period, which has implications to household income as they are cash crops and can adversely affect the household income level.

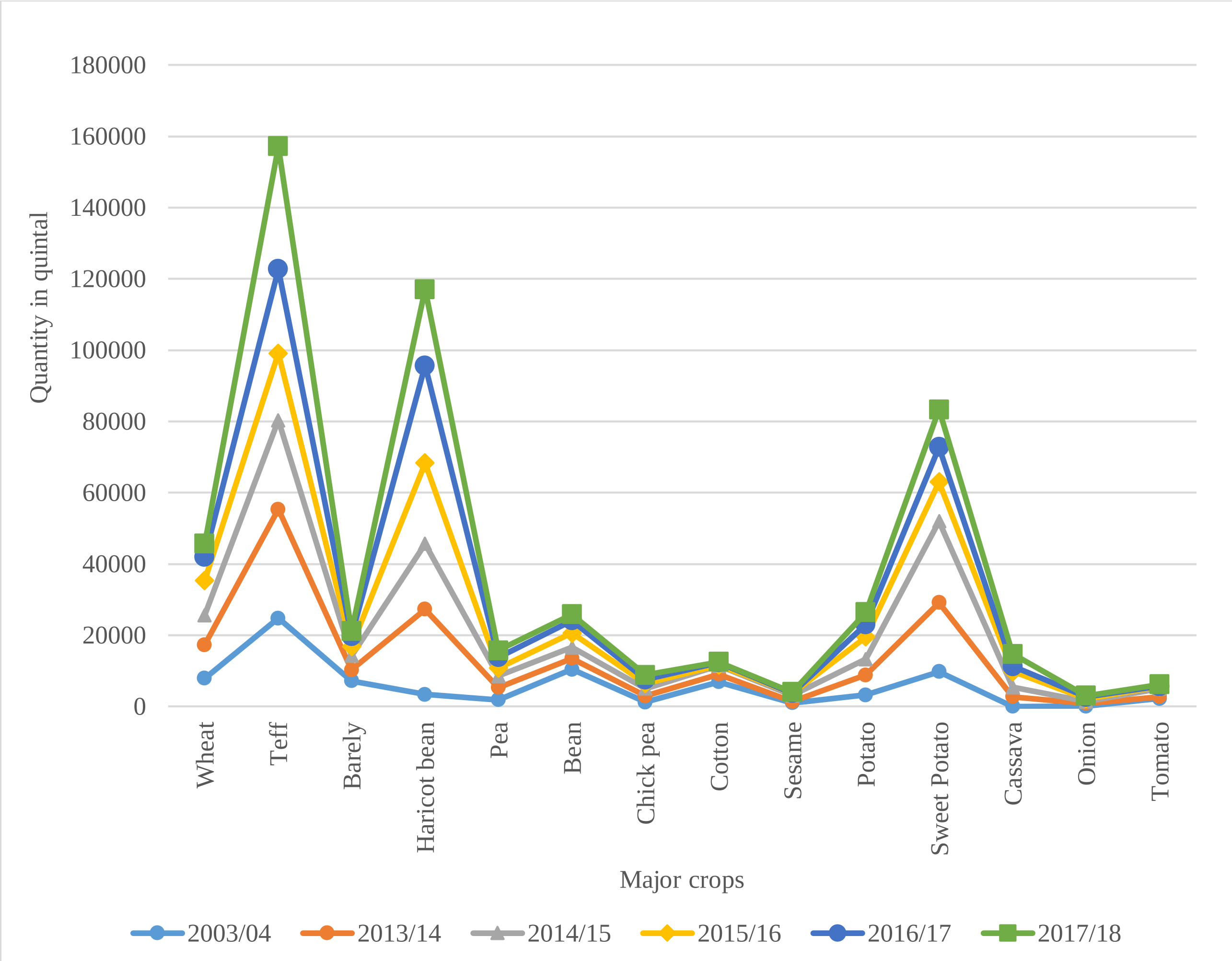

Figure 1.10Trends in the production of major crops (2003/4 to 2017/18)

1.8General methodological approaches

1.8.1 Overview of the research philosophy

For years' scholars have been debating on the philosophical[11]foundations or research paradigms[12]to study problems surrounding human beings and nature. Such debates and perspectives in relation to research paradigms divided scholars along the two major categories of research in social sciences are often identified-the quantitative and the qualitative (Jupp, 2006; Bryman, 2017; Walliman, 2017). Each paradigm bases on distinctive foundations and applies a specific approach to researching the social world. Bryman (2004, p. 19-20) identified three major characteristics in each that make the point. In quantitative research, a) the orientation-uses a deductive approach to test theories; b) Epistemology, is based on a positivist approach inherent in the natural sciences and the ontology-objectivist in that social reality is regarded as objective fact. In qualitative research**,** a) the orientation-uses an inductive approach to generate theories; b) Epistemology, it disregards positivism and basis on individual interpretation of social reality; and the ontology-constructionist, in this case, social reality is viewed as a continually shifting product of perception (Shaw, Dixon, & Jones, 2010; Williams, 2017).

Some scholars contended that mixed methods research has its own philosophical worldview: pragmatism. Hence, the pragmatists trust philosophically in using proceduresthat "work" for a specific research problem under study and that one should use multiple methods when understanding a research problem (Tashakkori & Teddlie, 1998; Tashakkori & Creswell, 2007). The dialectical position, contained by Greene and Caracelli(1997), suggests that researchers report the several worldviews they embrace results in, honoring worldviews as imperative, and thus, collect both quantitative and qualitativedata.

On this account, the pragmatism perspective was the general philosophical underpinning of this research. In support of this, Johnson, Onwuegbuzie, and Turner (2007) argued that most mixed research methods scholars have favored for some version of pragmatism as the most useful philosophy to support mixed methods research and rationalize the use of multiple methods in a single study (Migiro & Magangi, 2011; Brannen, 2017; Creswell & Clark, 2017). Moreover, Tolossa (2006) in his food security study indicated that pragmatism rejects the either-or approaches associated with the paradigm tension, and thus supports the application of mixed research method.

1.8.2 Research design and justifications

The choice of methodology depends more on the objectives of the study and the corresponding research questions than the preference of the researcher. Johnson and Onwuegbuzie (2004) thus conceptualized mixed methods research as "*the class of research where the researcher mixes or combines quantitative and qualitative research techniques, methods, approaches, concepts, or language into a single study*" (p. 17).Mixed research, according to Creswell and Clark (2017) is a research design with philosophical assumptions as well as methods of inquiry. As a methodology, it involves the philosophical assumptions that guide the direction of the collection and analysis of data and the mixture of qualitative and quantitative approaches in many phases in theresearch process. As a method, it focuses on collecting, analyzing, and mixing both quantitative and qualitative data in a single and series of studies. The recent understanding of mixed research is:

> An approach to research in the social, behavioral, and health sciences in which the investigator gathers both quantitative (closed-ended) and qualitative (open-ended) data, integrates the two, and then draws interpretations based on the combined strengths of both sets of data to understand research problems (Creswell, 2014p. 2).

Therefore, being governed by this definition, working principles and its characteristics, in this study, mixed research design was adapted as the general research approach. The quest for triangulation in multiple ways, such as analytical frameworks, data collection from multiple sources, multiple approaches of data analysis, and interpretation were considered as rationales to adapt mixed research design approach. In line with this, the central idea of mixed research design is that the combination of both forms of data give a better understanding of a research problem than either quantitative or qualitative data by itself (Creswell, 2014; Creswell & Clark, 2017). In general, using the mixed research methods, qualitative results have given new dimensions to concepts such as livelihood vulnerability, livelihood resilience capacities, climate variability and change that could not have been captured in quantitative measures/analysis of the concept and vice versa.

The mixed research design has many "strands"[13]**,**however, in this study, the convergent parallel mixed design was used to generate both qualitative and quantitative data concurrently. Creswell (2014), argues that in a convergent design, the direction of presentation must be driven by choices made vis-à-vis how the data interconnect to each other for integration.The study employed mixed the data collection where one data collection method supplied strengths to offset the weaknesses of the other. Such mixing resulted in a more complete understanding of a research problem results from collecting both quantitative and qualitative data (Creswell, 2014; Creswell & Clark, 2017). Due to the nature of the study and its guiding research questions, more weight was given to the quantitative approach, implying that the quantitative analysis would overweigh the qualitative one. The qualitative information was primarily used to support the quantitative findings in order to draw valid conclusions.

1.8.3 Sampling techniques, size and site selection

Sample households required for this study were selected using both probability and non-probability sampling techniques. In doing so, the study followed a multistage sampling technique to choose the study area among *Zones* in Southern Ethiopia, agro-ecologies within the *Zone*, *Kebeles* within the selected AEZ, and farm households and individuals from each *Kebele*for the data collection in different stages (Figure 1.11).

Stage 1: Selection of the study area

In the first stage, the study area (Wolaita *Zone*), among other *Zones* in the region was selected purposively. First, it is one of the most vulnerable and food-insecure *Zones* in Ethiopia and the Southern region (Jufare, 2008; Gecho *et al*., 2014a, b; Eneyew &Bekele, 2012; Abo&Kuma, 2015; Leza & Kuma, 2015; Tantu *et al*., 2017; Gazuma, 2018).Second, it is one of the most densely populated areas in the country withdegraded land and dominated by micro and smallholder farmers (Rhamato, 2007;Seyum, Tesfaye, Wiru, & Taye, 2014; Gecho*et al*., 2014a, b;Dana, 2015, Esayas *et al*.,2018a). Third, although some empirical studies were carried out in response to climate variability and change-induced shocks in different parts of Ethiopia, studies that focus on linking households livelihood vulnerability conditions to the changing climate and the search for livelihoodresilience capacities (absorptive, adaptive, and transformative) with the agro-ecological perspectives in the study area arenon-existent and/or very scanty.

Stage 2: Selection of sample AEZs

In stage two, out of the twelve *Weredas/*districtssubdivided among three AEZs,highland *(*Damote Gale), midland (Sodo Zuria), and lowland (Duguna Fango)-were purposively selected to represent three AEZs in the study area to analyze households' vulnerability to the changing climate and the corresponding resilience capacities (Table 1.7). In the selection of the study AEZs, three main factors were considered. The first one was the agro-ecolgoical location, i.e.,being *Dega* (high-land), *Woyna-Dega* (midland), and *Kolla* (lowland) in line with the traditional AEZs classification in Ethiopia and its proportion in the respective villages(Hurni, 1998; MoA, 2000). The second one was the availability of at least long years (i.e., 30 years) temperature and rainfall data to help the trend analysis (extreme and mean) of climatic variables.

The third factor was the physical distance between the meteorological stations designated to represent each AEZ and the number of stations within AEZ.

Table 1.7Sample households summarized in each Agro-ecological *Zone* in Wolaita *Zone*

Agro-Ecology	Selected *Wereda*	No. of *Kebeles*	*Kebele*	SelectedHHs	PPS (HHs)/*Kebele*
Highland	Damot Gale with 33% highland *Kebele*s	31	Aro-Wegera	1010	26
			Konsassa Pulassa	1247	32
			Wondra Bolosso	1248	32
Sub-total		31	3	3505	90 (22%)
Midland	Sodo Zuria with 87 % midland*Kebele*s	31	Humbo Larena	840	31
			Kokate Maria Chare	1422	58
			Zala Shasha	1090	40
			Wereza Lasho	1000	37
			Haba Gerera	1024	38
Sub-total		31	5	3576	198 (49%)
Lowland	Dugna Fango with 78 % of lowland *Kebele*s	27	Dando Werekicho	1226	44
			Ariso Woyde	936	33
			Duguna DamotShinka	1066	38
Sub-total		27	3	3228	115 (29%)
Grand total		89	11	12109	403

Stage 3: Selection of sample AEZ Kebeles

In stage three, based on Wolaita *Zone*Finance, Economic Development Bureau (WZFED) (2017) characterization of the AEZs, list of all *Kebeles* in the selected AEZs was used to cluster them into the respective AEZs (highland, midland, and lowland). This was to ensure that the selected *Kebele*s were from the respective and mutually exclusive AEZ. Then, using the list of *Kebeles'* and the overall proportion of AEZs in the study area, three highland AEZ *Kebeles*, five midland

AEZ *Kebeles*, and three lowland AEZ *Kebeles*were randomly selected with the help of computer-assisted random number generation technique in Excel 2016(Table 1.7).

Stage 4: Selection of sample households

In stage four, the probability proportional to sample size (PPS) method was employed to draw the sample households from each AEZ in each *Kebele*. In doing so, households list was collected from each *Kebele*administration representing each AEZ and the final unit (i.e., households in each AEZ *Kebele*) was selected randomly for face to face interview by trained enumerators. The required sample size was determined using Kothari (2004) sample size determination formulaequation 1.1.

$$n = \frac{Z^2 * p * q * N}{e^2(N-1) + Z^2 * p * q} + 10\% \quad (1.1)$$

Where, z=1.96 (95% confidence interval); p=sampling proportion, 0.5; q=1-p; e= precision level or error margin=0.05 (5%); N=total number of households in selected AEZs (sampling frame) =12,109; n=sample size required and 10% of n=contingency for both non-response rate and missing values.

Accordingly, a total of 198 (49%) of households were randomly selected from midland AEZ, followed by 115 (29 %) from lowland AEZ, and the remaining 90 (22 %) from highland AEZ. On the other hand, key informants for interviews and discussion participants were selected purposively, because these groups of respondents were believed to offer particularly relevant information, which has helped the study to complement data from other sources.

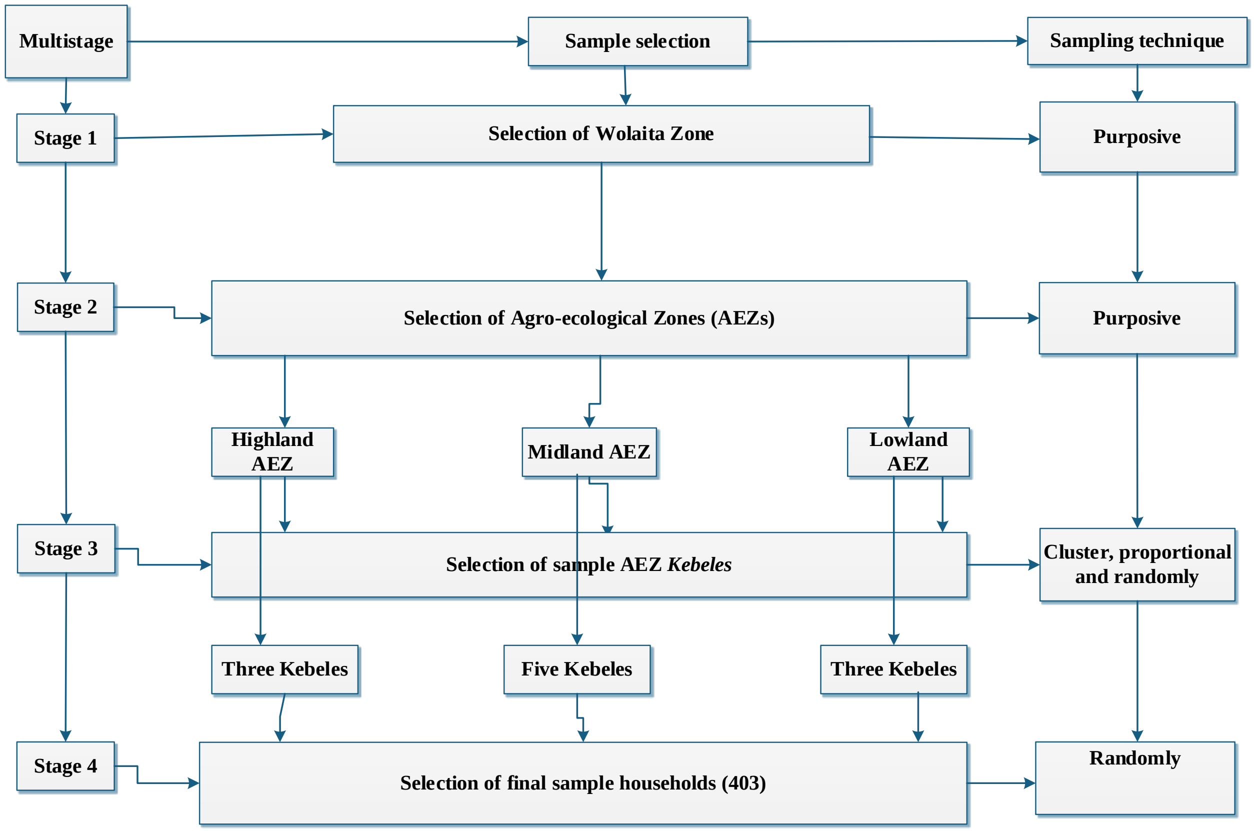

Figure 1.11 Sampling strategy: stages, sampling technique and sample size

1.8.4 Sources and types of data

Both qualitative and quantitative data were collected from primary and secondary sources. Primary data was collected from various individuals using household surveyquestionnaire , key informant interviews, focus group discussions, and field observations. Secondary data was collected through reviewing various sources such as *Zonal* level CSA (demographic and socioeconomic data of the study AEZs), Ethio-GIS (shape files for producing the socio-economic and biophysical maps of the study AEZs), secondary data pertaining to climate-induced shocks, trends of shocks, and vulnerability profiles obtained from federal, regional, *Zonal/Wereda* level agriculture and rural development office,and research reports and statistical data from relevant organizations working in the study area on related issues along the topic of discussions were considered for the purpose of data triangulation.Long years of gridded (4km by 4km) climatic data (1983-2014) including, daily maximum temperature, daily minimum temperature, and daily rainfall obtained from NMA for three main stations, namely Sodo town (midland AEZ), Boditi school (highland AEZ), and Bilate (lowland AEZ) (Figure 1.8 and Table 1.2)were also used as secondary sources.The gridded climate dataset helped to have broader perspectives of climate trend analysis in Wolaita *Zone*.

Finally, various policies, strategies and plans focusing on livelihood vulnerability, climate change, livelihood resilience as well as disaster risk management were thoroughly reviewed to gain insights on interventions taken so far to address households' vulnerability to the changing climate and build the resilience capacities of smallholder farmers to absorb, adapt, and transform from climate-induced shocks in Ethiopia, in general, and the study area, in particular. The secondary data sources were carefully checked for its accuracy, completeness, relevance as well as complementarities with other sources used to address the study objectives and arrive at valid conclusions.

1.8.5 Methods of data collection

Household surveyquestionnaire (HSQ)

All relevant primary data pertaining to the study objectives were generated from households using structured survey questionnaire. In this case, both open-ended and closed-ended type of questions that cover different themes and issues were prepared. The themes and topics covered in the survey questionnaire were households socio-economic and demographic data, data on major climate-induced shocks,data regarding households' perceptions of climate variability and change, households' livelihood vulnerability conditions to the changing climate (e.g., data on adaptive capacity, exposure, sensitivity), data on households' livelihood resilience capacity indicators such as, absorptive, adaptive, and transformative capacities and its determinants; and many other quantifiable data to fit the study objectives. The survey questionnaire was designed along specific indicators (i.e., indicator questions for socio-economic and demographic, major climate-induced shocks, livelihood vulnerability conditions, and livelihood resilience capacities among others). In this regard, some of the questions consistent with the study objectives were adapted from similar studies for the purpose of validity and reliability.

Once the tool design was completed, it was piloted in a nearby *Wereda*, which was not part of the sampled *Weredas*/AEZs to check for the appropriateness, completeness, and measurability of indicators proposed for the study. Then, errors, difficult terms, and scientific jargons were corrected for the actual data collection. Therefore, a total of 403 households were surveyed in face to face interviews conducted by trained enumerators[14].To maintain the data quality, the survey was administrated turn by turn in the respective AEZs with the presence of the researcher(Annex 1.1).

Key informant interviews (KIIs)

Key informant interview was employed as one of the qualitative information gathering methods. With the help of this method, information pertaining to some of the available and accessible assets in the study AEZs, vulnerability to shocks in each AEZ, perceptions to the changing climate over decades and preparedness towards the climate-induced shocks,livelihood resilience-building/interventions schemes taken so far to address the problems, and related information were obtained. The key informants of this study were the elderly people who lived for long years in the study AEZs, *Wereda* Agriculture and Rural Development Office Heads (one per *Wereda*), *Wereda* Disaster Risk Management Heads (one per *Wereda)*, *Zonal* level Meteorology Officers (one per *Zone)*, *Wereda*Early Warning and Disaster Risk Management Committee Representatives (one per *Wereda)*, *Wereda*Micro Finance Institution/Cooperative Promotion Office Heads (one per *Wereda)* and locally deployed NGOs (two at *Zonal* level) working on the study topic. Key informant interview guide was prepared to assist discussion with the selected key informants. Thus, a total of 15 KIIs were successfully conducted (Annex 1.2, Annex 1.3, and Annex 1.6).

Focus group discussion (FGD)

In a mixed research study, the main concern is triangulating data from different sources using different data gathering tools about the same issues under investigation. Therefore, FGD was used to elicit information among different groups of people who share common perspectives and experiences about the study themes. It was also intended to help explore the common areas of interest, disagreements, and agreements on a particular topic and setting. The discussion included mixed groups of people (i.e., female-headed households, male-headed households, community leaders, religious leaders, elderly people, and youths). It was a mixed FGD and consisted of seven to 12 individuals drawn from the above-mentioned groups of people in each AEZ, with one FGD in every AEZ *Kebele*, and totaling 11 FGDs were carried out, i.e.,three FGDs in the highland AEZ, three FGDs in the lowland AEZ, and five FGDs in the midland AEZ. In doing so, discussion checklist was prepared in line with the major themes of the study/objectives to generate the required information from the discussants. The use of FGD was primarily aimed to complement data from other sources and enable the study to consider the broader perspectives of households and community members in the study AEZs (Annex 1.4).

Field observation(FO)

Field observation was used to document some of the observable evidences or the facts of the study AEZs, which could not be captured through other techniques. Using this method, households' available and accessible assets, observable environmental changes or impacts due to climate variability and change, coping and adaptation strategies employed to shocks, intervention schemes put in place by different actors, and the overall situations were documented. To generate this information, an observation checklist was designed in view of the issues of observation, which was carried out in each AEZ to look into the similarities and differences between and among selected AEZs. The observation results were recorded in the form of photos and videos using electronic devices and other relevant materials, which in turn were used to supplement results from other data sources (Annex 1.5).

1.8.6 Methods of data analysis

Once the relevant data was generated from primary and secondary sources, it was coded, edited, and cleaned both manuallyand software assisted. The completed data was analyzed, summarized, and presented with the help of qualitative and quantitative techniques of data analysis. The qualitative information generated through key informant interviews, focus group discussions, and field observations followed the Bazeley (2009) ideas of thematic analysis (*three key strategies*), including description of data, classification of data, and seeing how concepts interconnect was applied to scientifically analyze, synthesize and report the findings. The results from qualitative studies were presented in the form of description (e.g., quotes) to complement findings from the quantitative survey.On the other hand, depending on the level of data measurements, descriptive statistics (mean, median, range, standard deviation, and coefficient of variation) were used to present the descriptive findings of each objective(Figure 1.13).

In addition, inferential statistics, for example, t-test, chi-square test, binary logit model, multiple linear regression (OLS), Mann-Kendal test (MK), Sen's Slope Estimation (SSE), and Quantile Regression (QR), were thoroughly used to answer the study objectives(Figure 1.12 and Figure 1.13). The computation of number of indices[15](Figure 1.12). In doing so, different software packages such as R, Origin-pro (7.0), SPSS (22.0), XLSTAT (16.0), and STATA (14.0)were employed to analyze, summarize, and discuss the quantitative data in different statistical forms. Vensim (6.3) and the Viso Professional Program (16.0) were used to model the statistical outputs and develop conceptual models. Arc-GIS (10.2) was used to map the study AEZs. Both Mendeley Desktop and Zotero were used as the reference management software while CS-pro (6.3) software was used to design and manage the survey instrument(Figure 1.12).

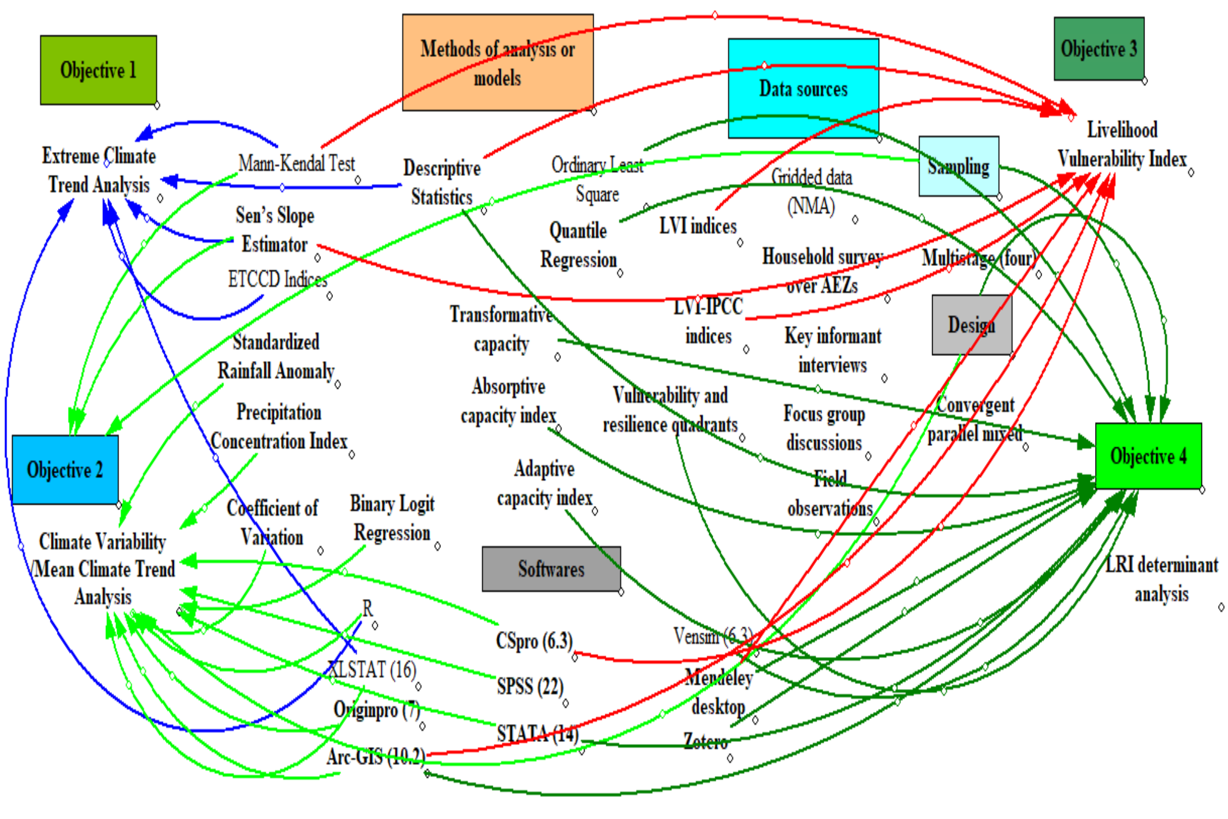

Figure 1.12Methodological summary by objective, data sources, and method of analysis

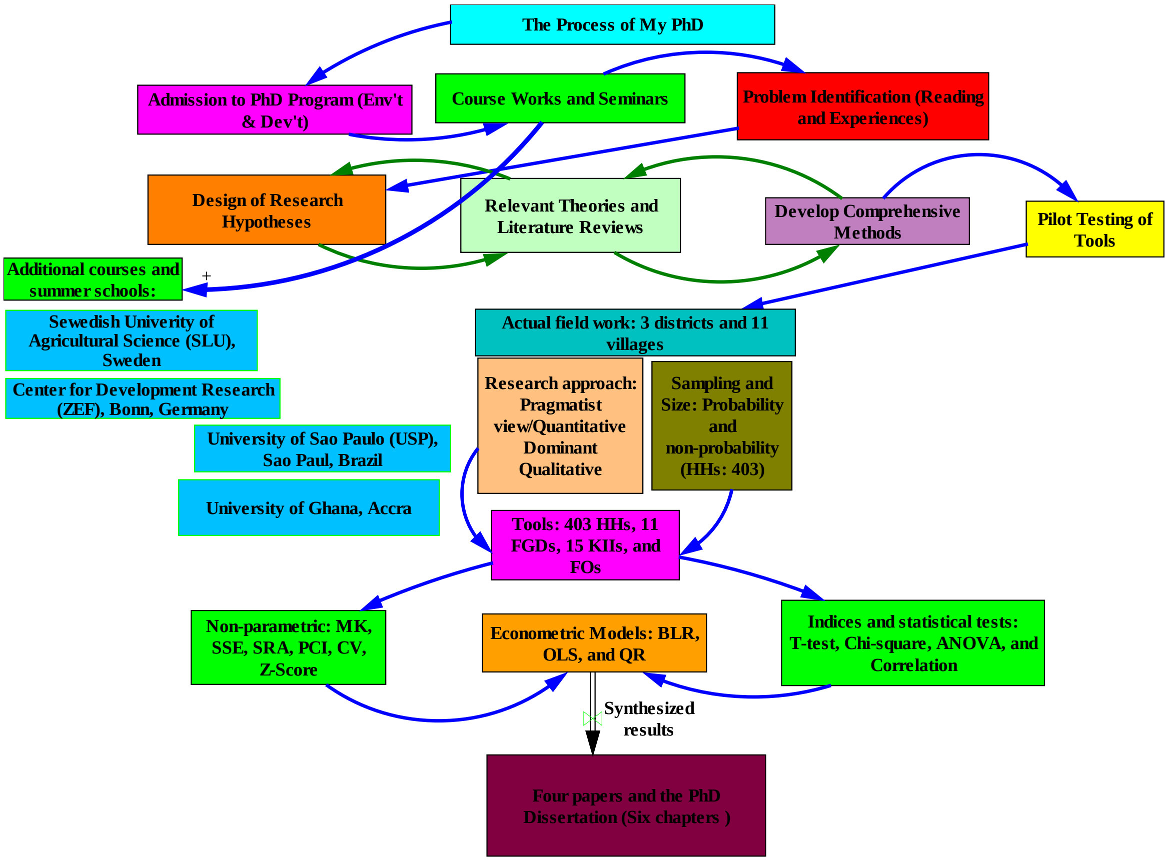

Figure 1.13 The whole process of the PhD

1.9Organization of the dissertation

This Ph.D. dissertation is organized into six chapters. Chapter one presents the general background of the study, problem statement, study objectives, basic research questions, delimitationand limitations of the study, and the general study area description. It also describes the general conceptual framework the study is based on. The general methodological approach of the study is part of this chapter. Chapter two outlines trends in extreme climate events in the three agro-ecological *zone*s covered by the study. Chapter three investigates climate variability and farmers' perception. Chapter four is devoted to assessing farmers'livelihood vulnerability to climate variability and changeamong the three agro-ecological settings. Chapter five specifically deals with measuring livelihood resilience capacities (absorptive, adaptive, and transformative) and the determinants of the households'level of resilience. Finally, chapter six synthesizesthe main findings of the core chapters of the study, describes scientific contributions of the study, potential policy implications, and areas of further studies.

Chapter two

2 Trends in extreme climate events over three agro-ecological *Zone*s of Southern Ethiopia

Abstract

The study aims to assess trends in extremes of surface temperature and precipitation through the application of the World Meteorological Organization-Expert Team on Climate Change Detection and Indices on datasets representing three agro-ecological *Zone*s in Southern Ethiopia. The indices are applied to daily temperature and precipitation data. Non-Parametric-Sen's slope estimator and Mann–Kendall's trend tests are used to detect the magnitude and statistical significance of changes in extreme climate, respectively. All agro-ecological *Zone*s have experienced both positive and negative trends of change in temperature extremes. Over three decades, warmest days, warmest nights, and coldest nights have shown significantly increasing trends except in the midland agro-ecology where warmest days decreased by (0.017 °C/year) ($p<0.05$). Temperature extreme's magnitude of change is higher in the highland agro-ecology and lower in the midland agro-ecology. The trend in the daily temperature range shows statistically significant decrease across agro-ecological *Zone*s($p<0.05$). A decreasing trend in the cold spell duration indicator was observed in all agro-ecological *Zone*s**,** the magnitude of change is (0.667 days/year) in lowland ($p<0.001$), (2.259 days/year) in midland and (1 day/year) in highland ($p<0.05$). On the other hand, the number of very wet days revealed a positive trend both in the midland and highland agro-ecological *Zone*s ($p<0.05$). Overall, it is observed that warm extremes are increasing while cold extremes are decreasing, suggesting considerable changes in the agro-ecological *zone*s.

Keywords: Agro-ecological *Zone*, extreme event, rainfall, temperature, Ethiopia

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2.1 Introduction

The IPCC report shows that climate change is evident by high frequency in climate extreme events including, flooding, drought, sea-level rise, and heatwaves (IPCC, 2013). Various studies have shown changes in the occurrence and severity of climate extreme events, along with the variability of weather patterns, causing substantial impacts on human and natural systems (IPCC, 2007; IPCC, 2014; Thornton *et al*., 2014). Climate change impacts, however, are differently experienced in different parts of the world owing to various geographic settings and socioeconomic factors (IPCC, 2014; Adger, 2011). With a projected 3 to 4 °C temperature increase, climate change impact in the future will result in more hostile environments, associated with increases in the frequency and severity of floods and droughts (IPCC, 2012; IPCC, 2014). Furthermore, the IPCC reports illustrate that the intensity and occurrence of extreme events are expected to increase in different parts of Africa (IPCC, 2013; IPCC, 2014). Climate models have shown that climate impacts will be severe in many areas of Africa, including East Africa (Sylla, Elguindi, Giorgi, &Wisser, 2016; Ongoma, Chen, & Omony, 2018a), primarily associated with changes in atmospheric forcing due to anthropogenic causes (Peterson, Hoerling, Stott, & Herring, 2013).

Due to the adverse effects of climate variability and change, Ethiopia is considered to be one of the most vulnerable countries (World Bank,2010; Conway&Schipper, 2011). The country largely suffers from hazards linked to high rainfall variability (EPCC,2015; Degefu, Rowell, & Bewket, 2017) and climate extreme events (Berhanu &Beyene, 2015). It has experienced droughts and floods from the 1980s onwards (World Bank, 2010); and since 1900 the country has recorded 47 major floods that killed about 2,000 people and affected close to 2.2 million people (You &Ringler, 2010). Ethiopia also experienced 12 major droughts between 1900 and 2010 that claimed the lives of over 400,000 people and the number of those affected was over 54 million (You &Ringler, 2010). Very recently, the 2015 El Niño-induced drought has caused food insecurity among 10.2 million people; one of the highest on record (FAO, 2016a). Moreover, it is projected that Ethiopia will face serious and damaging impacts resulting from changing climate patterns in the future (Savage *et al*., 2015).

Owing to the high probability of changes in climate extremes and the negative economic, social and environmental impacts (IPCC, 2007; Frank*et al*., 2015; Trenberth, Fasullo, & Shepherd, 2015), due consideration has been given to the analysis of climate extreme events in recent years (Trenberth, 2011). This is because climate extremes respond more sensitively to climate change than changes in the average climates (Alexander *et al*., 2007; National Academies of Sciences, Engineering, and Medicine, 2016). Furthermore, extreme events affect the ecosystems much more than changes in the mean climate (Peterson &Manton, 2008; Tierney, Smerdon, Anchukaitis, & Seager, 2013). Following the IPCC (2012) definition, in this study, an “extreme event” is used to illustrate the occurrence of a value of a weather or climate variable above or below a threshold value, generally occurring at the tails of the probability density function (PDF) of the range of observed values of the variable within a defined climate reference period.

Temperature and rainfall are the two most significant and sensitive climatic elements in tropical regions. Data regarding extreme climates and their characteristics are essential to identify, plan, implement, monitor and evaluate different socio-economic activities in developing economies such as Ethiopia. In Ethiopia, responding to the negative impacts of extreme climates on the smallholder lives and livelihoods requires detailed studies that document the extent and trends of changes in the extreme climate events. Thus, this study considers the local level analysis of extreme climate events as a case study, which may help to react timely to the associated shocks.

Some empirical studies have attempted to analyze the extreme climatic events in Ethiopia but found mixed results owing to contextual differences. Despite varied results in the magnitude of change observed, a growing body of literature now points to significant trends in precipitation and temperature extremes. For example, a negative trend was observed in seasonal extreme rainfall (Seleshi &Camberlin, 2006) while mixed trends of changes were reported in rainfall extremes (Bewket &Conway, 2007; Kebede &Bewket, 2009; Shang, Yan, Gebremichael, & Ayalew, 2011; Kiros, 2017). Several empirical studies suggest positive trends in air temperature and negative trends in rainfall (Jury& Funk, 2013; Mekasha, Tesfaye, & Duncan, 2014; Gummadi *et al*., 2017; Suryabhagavan, 2017).A study by Viste, Korecha, and Sorteberg (2013) reported that even though the degree of drying varies spatially, all the studied areas experienced drought at annual scales in Ethiopia. Zeleke, Giorgi, Diro, and Zaitchik (2017) documented that south and southwestern regions of Ethiopia have experienced drying while the central mountainous, north, and northwestern regions had no observed long-term trends. Recently,Worku, Teferi, Bantider, and Dile (2018) reported warming trend in extreme temperature indices while an increase in rainfall extreme events in Jemma Sub-Basin, Upper Blue Nile Basin. However, Kebede, Diekkrüger, and Edossa (2017) reported neither a clear monotonic trend in dry spells nor significant variation in the rainfall duration, onset, and cessation.

In Ethiopia, different studies reported that there has been inconsistency of patterns in the precipitation extremes(Seleshi &Camberlin, 2006; Bewket &Conway, 2007;Kebede &Bewket, 2009; Shang *et al*., 2011; Degefu &Bewket, 2014; Mekasha *et al*., 2014; Gummadi*et al*., 2017; Kiros, 2017; Worku*et al*., 2018).Regardless of the inconsistency in the rainfall extremes in Ethiopia, recent evidence show that the frequency of the occurrences of extreme events and their variability has increased over the last 20 years (IPCC, 2014; Fischer &Knutti, 2015; Herring, 2015; Worku*et al*., 2018). In the context of the study area, a recent study by Degefu and Bewket (2014) revealed that the geographic distribution on the occurrence and magnitude of observed drought events were complex.

Although the above-mentioned studies have documented trends in climate extremes at national, regional, and local levels, the studies have been reporting different patterns in the climate extremes mostly focusing on the national level analysis with a lot of emphasis ondrought. A few studies have examined variations in rainfall extremes using selected indices at national and sub-national levels, which may not fully explain the situation at the local level. Though others have assessed trends of climate extremes, most of the studies are spatially confined to the northern part of Ethiopia with the exception of the recent study by Degefu and Bewket (2014) that analyzed trends of climate extremes in Omo-Ghibe River basin. Therefore, the existing information on climate extremes is limited in scope, fragmented in coverage, and does not provide complete perspectives on the complex topography, relief, and agro-ecological settings in Ethiopia (Bewket &Conway, 2007;McSweeney *et al*., 2008).

Unlike earlier studies, this study focuses on and dis-aggregation by AEZsbecause of the increasing importance of agro-ecological based analysis in the face of changing climate extremes. Case studies based on such a perspective (e.g., *climate resilience to farm productivity*) in the context of climate variability and change are very important (Silici, 2014). This reveals on the importance of agro-ecological based approach as one of the scientific discipline, sustainable farming approach and social movement (Silici, 2014). Moreover, with the changing climate extremes and their adverse effects on peoples' livelihoods, some attempts have been made to promote "agro-ecology as the sustainable alternative to climate change crisis" (Ojha *et al*., 2014). In the Ethiopian context, existing evidence suggest that different agro-climatic *Zone*s are found. Traditionally, the agro-ecologies have been classified into five categories based on altitude, rainfall, and temperature (Zerihun, 1999; MoA, 2000).

More importantly, the design and development of local-level climate adaptation options and enhancing early warning systems require us to understand the characteristics and trends in climate extreme events at different geographical scales. This study thus addsvalue to the advancing field of study-climate extreme literature by offering first-hand evidence both on the temperature and precipitation based indices at AEZs in Southern Ethiopia. It also gives new insights in the application of gridded data at a micro-level where finding complete station data is a serious challenge. The study, by employing climate extreme indices–as one way to investigate climate variability and change in the study area, can serve as reference for similar studies in the future.

In general, this study intends to better the understanding of changes and trends in extreme climate events and their frequency, and duration, and variability over three AEZs of Wolaita *Zone*, Southern Ethiopia. It aims to, a) analyze the magnitude and frequency of occurrence of extreme temperature events and b) analyze the magnitude and frequency of occurrence of extreme precipitation events in AEZs.

2.2Methodology

2.2.1 Data

The study is based on gridded dataset (4 km by 4 km spatial resolution) of daily maximum and minimum temperatures, and daily total rainfall from 1983 to 2014. The gridded dataset combines two datasets. The first is station data (rainfall and temperature) from the national network managed by the Ethiopian National Meteorological Services Agency (NMA). The second dataset is satellite rainfall and temperature estimations from European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) and the US National Aeronautics and Space Administration (NASA). In other words, the gridded dataset integrated quality-controlled station data from the national observation network with locally calibrated satellite-derived data that were used to fill spatial and temporal gaps in the Ethiopian national observations. Data reconstruction was undertaken by the NMA in partnership with International Research Institute for Climate and Society at Columbia University, USA. Whereas, data calibration and validation were carried out by Reading University, UK.

As mentioned by Mengistu, Bewket, and Lal (2014) in the Upper Nile Basin, Ethiopia, station-based data in Wolaita *Zone* had also many missing values, poor in quality, measurement errors, and lack continuous data both for temperature and precipitation. Due to these reasons, the preference was given to the use of gridded dataset, which had better data quality and daily minimum and maximum temperature and daily total precipitation data was available between 1983 and 2014 for the studied AEZs as opposed to using the available station-based dataset. The data used for this study can be found at Ethiopian National Meteorological Services Agency (www.ethiomet.gov.et/) for the climatic stations located over three Agro-ecological *Zone*s.

On the other hand, this study considered three existing stations, which are located over the AEZs using the gridded dataset for the purpose of comparison by AEZ, which in turn was used to represent each AEZ with the available climate data over the study period (1983-2014). The stations include Bilate (Lowland), Wolaita (Midland), and Boditi School (Highland)(Figure 1.8).The stations were selected purposively as they have long years (over 30 years) of observed temperature and rainfall data. The analysis period, 1983-2014, was chosen due to data availability within the selected periods and to explore the recent change in extreme temperature and rainfall across the study AEZs. Data quality control was carried out using ClimPACT2 Software in R (Alexander, Yang, & Perkins, 2018). Data quality was tested in order to label potentially wrong values and to remove them from the analysis. Unrealistic values, such as daily maximum temperature less than or equal to daily minimum temperature were identified and set to missing values. The reference period of 1983–2000 was chosen out of the full-time range (1983-2014) mainly for the calculation of the percentile-based indices.

2.2.2 Method of data analysis

In an effort to investigate the existence of trends in time series of both temperature and rainfall indices obtained from daily data, the non-parametric Mann-Kendall (MK) test statistic (Kendall, 1938; Mann, 1945) and Sen's estimator test (Sen, 1968) were used.

Mann-Kendall test

The MK method was developed by Kendall (1938) and first applied by Mann (1945) to test whether there is a trend in climate extremes. The method uses the correlation between the ranks of a time series and their sequence. A hypothesis test is formulated as null hypothesis (H_0) when there is no trend and the alternate hypothesis (H_1), as a trend in climate extremes – where there is an increasing or decreasing monotonic trend. The Z score is calculated and the confidence limits of the standard normal Z are equally determined. For a ranked set of observations n, $X = x_1, x_3, \ldots, x_n$, the MK trend statistic S is calculated using equation 2.1;

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}\left(x_j - x_i\right) \qquad (2.1)$$

where x_j are the sequential data values, n is the data length of the time-series, and

$$\operatorname{sgn}\left(x_j - x_i\right) = \begin{cases} 1 & x_j > x_i \\ 0 & x_j = x_i \\ -1 & x_j < x_i \end{cases}$$

The variance of S is computed using equation 2.2;

$$\operatorname{Var}(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{p} t_i(t_i - 1)(2t_i + 5)}{18} \qquad (2.2)$$

where n is the number of data points, p is the number of tied groups, and t_i is the number of data values in the p^{th} group. A tied group is sample data having the same value, where there is zero difference between compared values. The summation aspect of equation 2.2 can be disregarded if there are no tied groups. The significance of a trend is computed by the Z score using equation 2.3;

$$Z = \frac{S-1}{\sqrt{\mathrm{Var}(S)}} \quad \text{if } S>0$$
$$= 0 \quad \text{if } S=0$$
$$= \frac{S+1}{\sqrt{\mathrm{Var}(S)}} \quad \text{if } S<0 \qquad (2.3)$$

When Z value exceeds either of the confidence limit lines, it indicates a significant trend at a given significance level. In that case, H_0 is rejected and in place H_1 is accepted. The method has been successfully applied in similar studies, including Ethiopia (Degefu &Bewket, 2014; Teferi *et al*., 2015; Gummadi *et al*., 2017; Ongoma *et al*., 2018a; Ongoma, Chen, Gao, Nyongesa, & Polong, 2018b; Workue*t al*., 2018).

Sen's slope estimator test

The Sen's slope estimator (Sen, 1968) is used to estimate the magnitude of trends in the time series data. In this case, if a linear trend is present in a time series, then the true slope of the trend is estimated using a Sen-Theil trend line (Theil, 1950; Sen, 1968), which is an alternative to linear regression and used in conjunction with the MK test. The slope (T_i) of all data pairs is computed as given in equation 2.4;

$$T_i = \frac{X_j - X_k}{j-k} \; for\; i = 1, 2, \ldots N \qquad (2.4)$$

where X_j and X_k are considered as data values at time j and k $(j > k)$correspondingly. The median of these N values of T_i is represented as Sen's estimator of slope, which is given by equation 2.5;

$$Q_i = \begin{cases} T_{\frac{N+1}{2}}, N \text{ is odd} \\ \frac{1}{2}\left(T_{\frac{N}{2}} + T_{\frac{N+2}{2}}\right), N \text{ is even} \end{cases} \quad (2.5)$$

Sen's estimator is computed as $Q_{med} = T_{(N+1)/2}$ if N appears odd, and it is considered as $Q_{med} = T_{\frac{N}{2}} + T_{\frac{N+2}{2}}$ if N appears even. Finally, Q_{med} is calculated by a two-sided test at 100 $(1-\alpha)\%$ confidence interval, which in turn helps to get the true slope through the non-parametric test. A positive value of Q_i indicates an increasing trend and a negative value of Q_i gives a decreasing trend in the time series (Jain &Kumar, 2012). Various studies applied Sen's slope estimator test to identify the magnitude of trend in the time series data (Jain &Kumar, 2012; Degefu &Bewket, 2014; Teferi *et al*., 2015; Gummadi *et al*., 2017; Ongoma *et al*., 2018a; Ongoma *et al.*, 2018b; Worku*et al*., 2018). Both the Mann-Kendall test and Sen's slope estimator test were computed using R software.

Climate extreme indices

The ETCCDI defined 27 core climate extreme indices (http://etccdi.pacificclimate.org). The indices illustrate the frequency, largeness, and persistence of extremes. The use of indices is decided by the international community that aims to monitor changes in "moderate" extremes. This approach aimed to promote studies on climate extremes with the use of indices that are statistically strong includes a range of climates, and own a high signal-to-noise ratio. From the core extreme indices, 11 extreme temperatures and, 9 extreme precipitation indices were selected for this study. All trends for indices selected have been calculated annually using the ClimPACT2 software in R. The indices were selected mainly for assessment of the various components of the temperature and precipitation extreme events (Table 2.1). The chosen indices signify extreme events that happen frequently per season or year providing them more robust statistical properties than measures of extremes (Choi *et al*., 2009). Moreover, a study by Zhang *et al*. (2011) has widely discussed on the moderate extreme indices adapted in this study.

Table 2.1 ETCCDI precipitation and temperature indices selected for this study

Indices	Indicator name	Definition	Units
Temperature-based indices			
TX90p	Occurrence of Warm days	Percentage of days when TX > 90^{th} percentile of 1983-2014	%
TX10p	Occurrence of Cool days	Percentage of days when TX < 10^{th} percentile of 1983-2014	%
TN90p	Occurrence of Warm nights	Percentage of days when TN > 90^{th} percentile of 1983-2014	%
TN10p	Occurrence of Cool nights	Percentage of days when TN < 10^{th} percentile of 1983-2014	%
TXx	Warmest day	Annual maximum value of daily maximum temperature	ºC
TNx	Warmest night	Annual maximum value of daily minimum temperature	ºC
TXn	Coldest day	Annual minimum value of daily maximum temperature	ºC
TNn	Coldest night	Annual minimum value of daily minimum temperature	ºC
WSDI	Warm spell duration indicator	Number of days contributing to a warm period	days
CSDI	Cold spell duration indicator	Number of days contributing to a cold period	days
DTR	Diurnal temperature range	Mean difference between daily maximum temperature and minimum temperature	ºC
Precipitation-based indices			
SDII	Simple daily intensity index	Mean precipitation amount on a wet day	mm/da
CDD	Consecutive dry days	Maximum number of consecutive days having precipitation<1mm	days
CWD	Consecutive wet days	Maximum length of wet spell	days
R10mm	Number of days	Annual count of days when precipitation>= 10 mm	days
R20mm	Number of very heavy precipitation days	Annual count of days when precipitation>=20mm	days
RX1day	Max 1-day precipitation	Maximum amount of rain that falls in one day	mm
RX5day	Max 5-day precipitation	Maximum amount of rain that falls in five consecutive days	mm
R95p	Very wet days	Annual sum of daily PR > 95th percentile of 1983-2014	mm
R99p	Extremely wet days	Annual sum of daily PR > 99th percentile of 1983-2014	mm

2.3Results and discussion

2.3.1 Trends in temperature extremes

Warm days (TX90p) and warm nights (TN90p)

Trends for the temperature indices for the three AEZs are shown in Table 2.2. From the percentile-based temperature indices, significantly increasing trend in the frequency of warm days (TX90p) was observed both in the lowland (Figure 2.1 (A)) and highland AEZs (Figure 2.1(C)) ($p<0.05$ and $p<0.001$), respectively. The TX90p shows an insignificant decreasing trend in the midland AEZ (Figure 2.1 (B)). Similar to the frequency of TX90p reported in lowland and in highland AEZs, the occurrence of warm nights (TN90p) have shown very significant increasing trends ($p<0.001$) (Figure 2.1(a)) for the lowland AEZ and (Figure 2.1 (c)) for highland AEZ, respectively.

Table 2.2Trends in temperature extreme indices per year by AEZs

Index	Units	Lowland AEZ		Midland AEZ		Highland AEZ	
		MK_Z(direction)	Sen's slope	MK_Z (direction)	Sen's slope	MK_Z (direction)	Sen's slope
TX90p	%	↑(0.315)*	0.326 *	↓(-0.177)	-1.501	↑(0.480)***	0.565 ***
TX10p	%	↓(-0.234)	-0.158	↓(-0.089)	-0.05	↓(-0.363)*	-0.284 *
TN90p	%	↑ (0.552)***	0.547 ***	↑(0.198)	0.234	↑(0.572)***	0.61 ***
TN10p	%	↓(-0.659)***	-0.349 ***	↓(-0.612)***	-0.605 ***	↓(-0.686)***	-0.264 ***
TXx	°C	↑(0.258)*	0.025 *	↓(-0.252)*	-0.017 *	↑(0.523)***	0.042 ***
TXn	°C	↑(0.137)	0.01	↑(0.141)	0.012	↑(0.290)*	0.024 *
TNx	°C	↑(0.462)***	0.055 ***	↑(0.407)***	0.037 ***	↑(0.597)***	0.063 ***
TNn	°C	↑(0.653)***	0.078 ***	↑(0.581)***	0.075***	↑(0.690)***	0.084 ***
WSDI	days	↑(0.156)	2.00	↓(-0.322)	-1.000	↑(0.270)	2.667
CSDI	days	↓(-0.652)***	-0.667 ***	↓ (-0.566)*	-2.259 *	↓(-0.591)*	-1.00 *
DTR	°C	↓(-0.367)*	-0.052 *	↓(-0.423)***	-0.053 ***	↓(-0.282)*	-0.043 *

*** $p \leq 0.001$; ** $p \leq 0.01$; *$p \leq 0.05$. Note: ↑ (increasing trend)and ↓ (decreasing trend)

The increasing trend observed in the two AEZs are in agreement with results from the three eco-environments in Ethiopia (Mekasha *et al*., 2014) and Worku *et al*. (2018). On the other hand, the midland AEZ experienced insignificant increasing trend in the TN90p (Figure 2.1 (B)). The annual number of TN90p and TX90p show significant warming anomalies for the period 1983–2014 both in the lowland and highland AEZs. The TX90p reaches its peak in 2009 for the lowland AEZ (Figure 2.1 (A)) and in 2012 for the highland AEZ (Figure 2.1 (C)). On the other hand, TN90p peaked in 2010 in the lowland AEZ (Figure 2.1 (a)) and in 2014 for the highland AEZ (Figure 2.1 (c)). In general, from 2008 onwards, warming anomalies are consistently increasing in all AEZs.

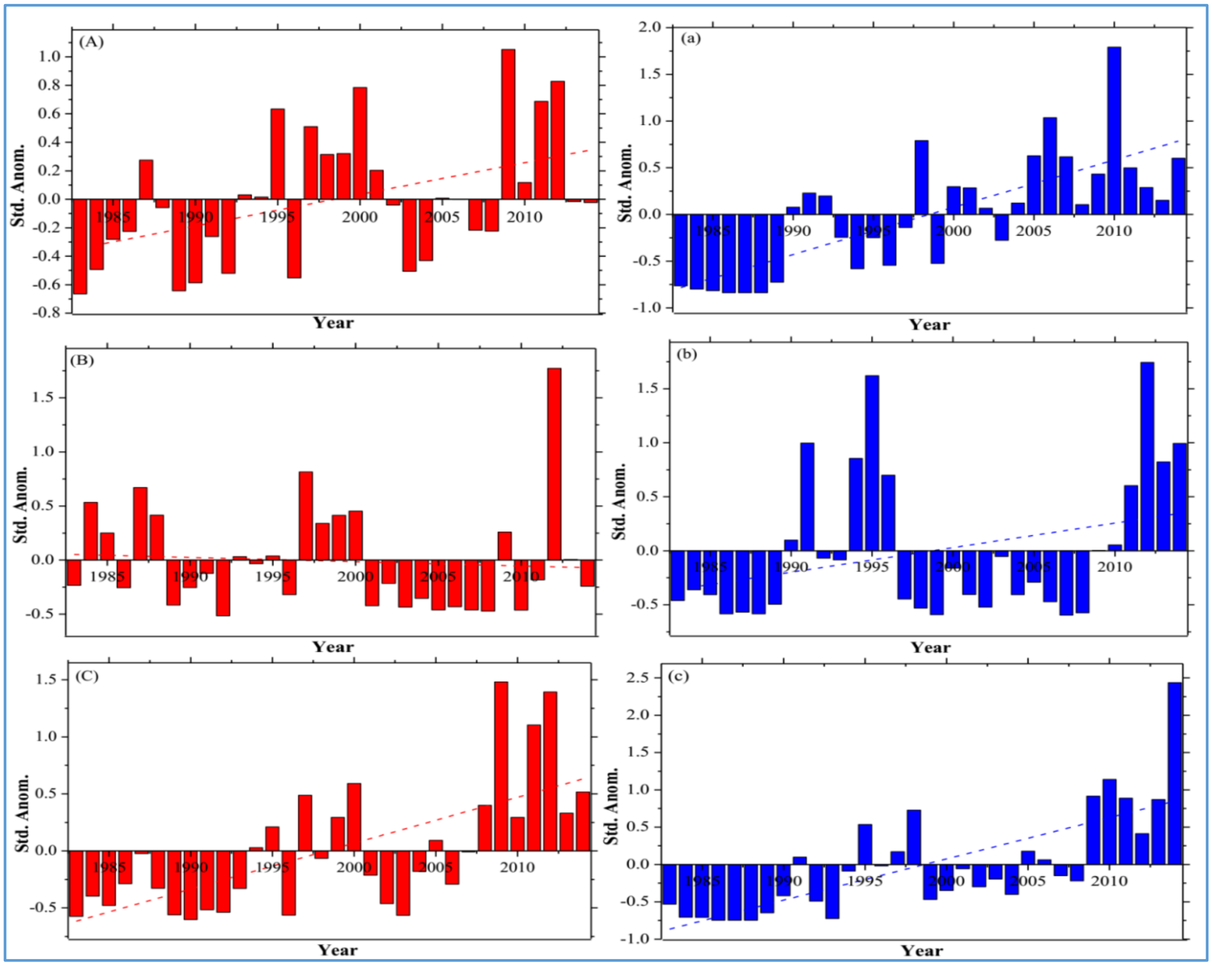

Figure 2.1 Standardized anomalies of warm days (TX90p) over three agro-ecological *Zone*s, (A) Lowland, (B) Midland, (C) Highland (left) and for warm nights (TN90p), (a) Lowland, (b) Midland, (c) Highland (right), for the period, 1983-2014

Cool days (TX10p) and cool nights (TN10p)

Insignificant decreasing trend in the frequency of cool days (TX10p) was observed in the lowland AEZ (Figure 2.2(A)) and midland AEZ (Figure 2.2 (B), respectively. However, TX10p shows a decreasing trend in the highland AEZ ($p<0.05$) (Figure 2.2 (C)). Concerning the frequency of cool nights (TN10p), a very significant decreasing trend was observed in all AEZs ($p<0.001$), the result is in line with the recent work by Worku *et al*. (2018). The negative anomalies are consistently declining since the late 1980s both in the lowland (Figure 2.2 (a)) and highland AEZs (Figure 2.2 (c)), respectively. On the other hand, except for the years 1997 to 1999, the midland AEZ also experienced negative anomalies for the TN10p between late 1980s and 2014 (Figure 2.2 (b)). All the AEZs have experienced a very significant decreasing trend in the TN10p over the period between 1983 and 2014. The significantly increasing trends in the occurrences of TX90p and TN90p while decreasing trends in TX10p and TN10p are in agreement with results from other studies that have analyzed these trends in different parts of the world(Donat *et al*., 2013; Omondi *et al*., 2014; Lin, Horowitz, Payton, Fiore, & Tonnesen, 2017; Ongoma &Chen, 2017).

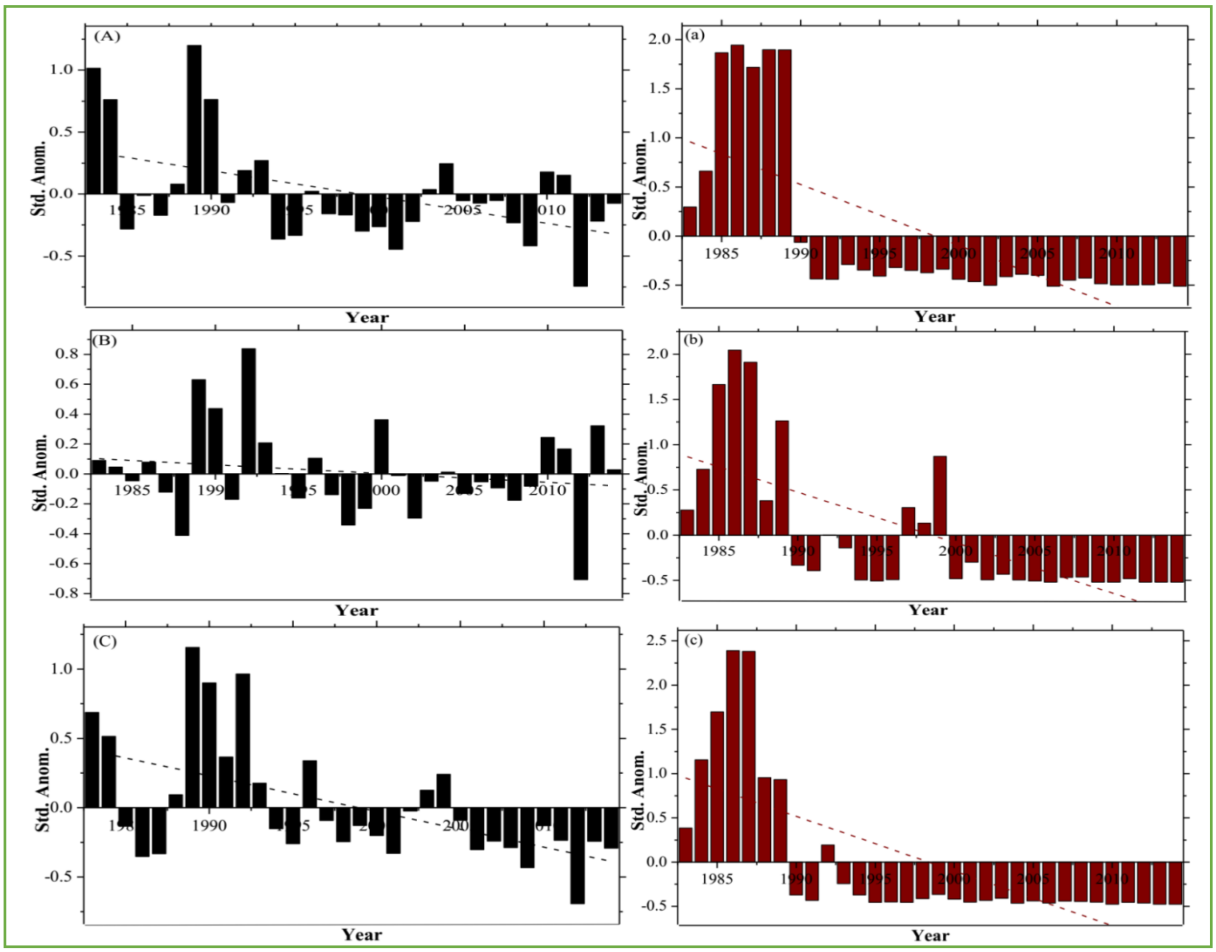

Figure 2.2Standardized anomalies of cool days (TX10p), over three agro-ecological *Zone*s, (A) Lowland, (B) Midland, (C) Highland (left) and for cool nights (TN10p), (a) Lowland, (b) Midland, (c) Highland (right), for the period, 1983-2014

In summary, two of the AEZs have experienced significant increases in TX90p and TN90p over the period between 1983 and 2014 while no significant trends were observed for all indices in the midland AEZ except for TN10p. The figures are indicative of the increasing trends in the warm extremes and decreasing trends in the cold extremes. These figures clearly show significant warming. In view of this, Workue*t al*. (2018) reported similar pattern of trends both in cold and warm extremes in Upper Blue Nile Basin. Moreover, empirical studies in East Africa, including Ethiopia, suggest that the frequencies of warm days and nights compared to the initial time showed a large increase vis-à-vis the number of cold nights per year beyond the 90th percentile threshold (Zhang *et al*., 2011).

Warmest day (TXx) and coldest day (TXn)

The trend in the warmest day (TXx) is statistically significant with the magnitude of change being (0.025°C /year) ($p<0.05$) for the lowland AEZ while the magnitude of change in the highland AEZ was observed to be (0.042 °C /year) ($p<0.001$). The TXx in the midland AEZ showed a statistically significant decreasing trend (0.017 °C /year) ($p<0.05$) Table 2.2.

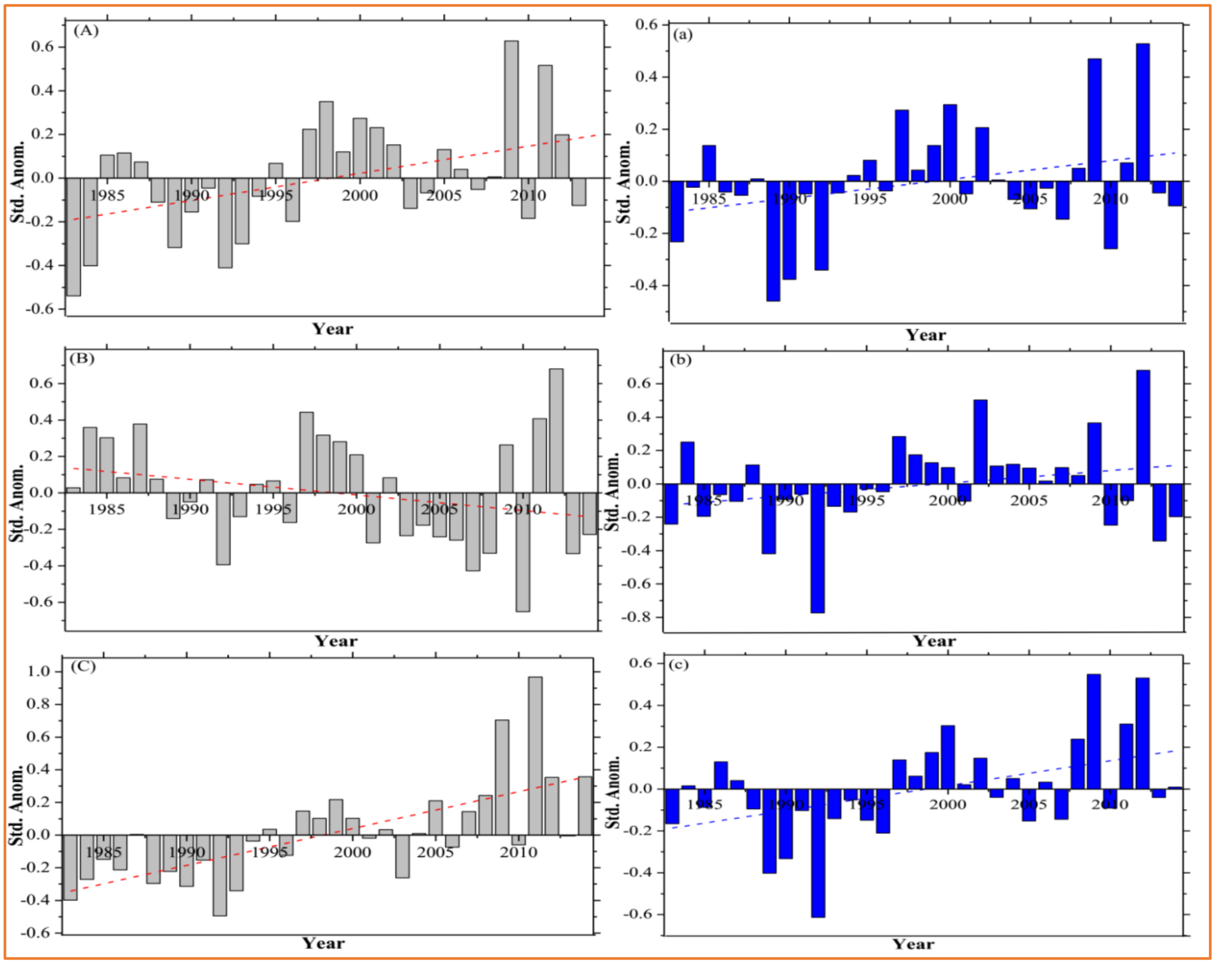

Figure 2.3Standardized anomalies of warmest day (TXx**)**, over three agro-ecological *Zone*s, (A) Lowland, (B) Midland, (C) Highland (left) and for coldest day (TXn**)**, (a) Lowland, (b) Midland, (c) Highland (right), for the period, 1983-2014

The TXx reached its peak in 2009 for the lowland AEZ (Figure 2.3 (A)), in 2012 for the midland AEZ (Figure 2.3 (B)), and in 2011 for the highland AEZ (Figure 2.3 (C)). The temperature of the coldest day (TXn) is significantly increasing in the highland AEZ with the magnitude of change being (0.024 °C/year) ($p<0.05$) while this index is insignificant in the lowland and midland AEZs (Figure 2.3 (a)) and Figure 2.3 (b)). A study by Mekasha *et al*. (2014) reported a similar trend in Ethiopia where TXn values were not significantly shifting over the study periods in all the sampled stations.

Warmest night (TNx) and coldest night (TNn)

The trend in the warmest night (TNx) is significantly increasing in all AEZs (p<0.001). In line with this, significant increase in warm nights was also reported in previous studies (Lin *et al*., 2017; Worku *et al*., 2018). The magnitude of change was reported to be (0.055 °C/year) for the lowland AEZ, (0.037 °C /year) for the midland AEZ, and (0.063 °C/year) for the highland AEZ. In relative terms, the highland AEZ has experienced higher magnitude of change in the TNx than both the midland and lowland AEZs Table 2.2.

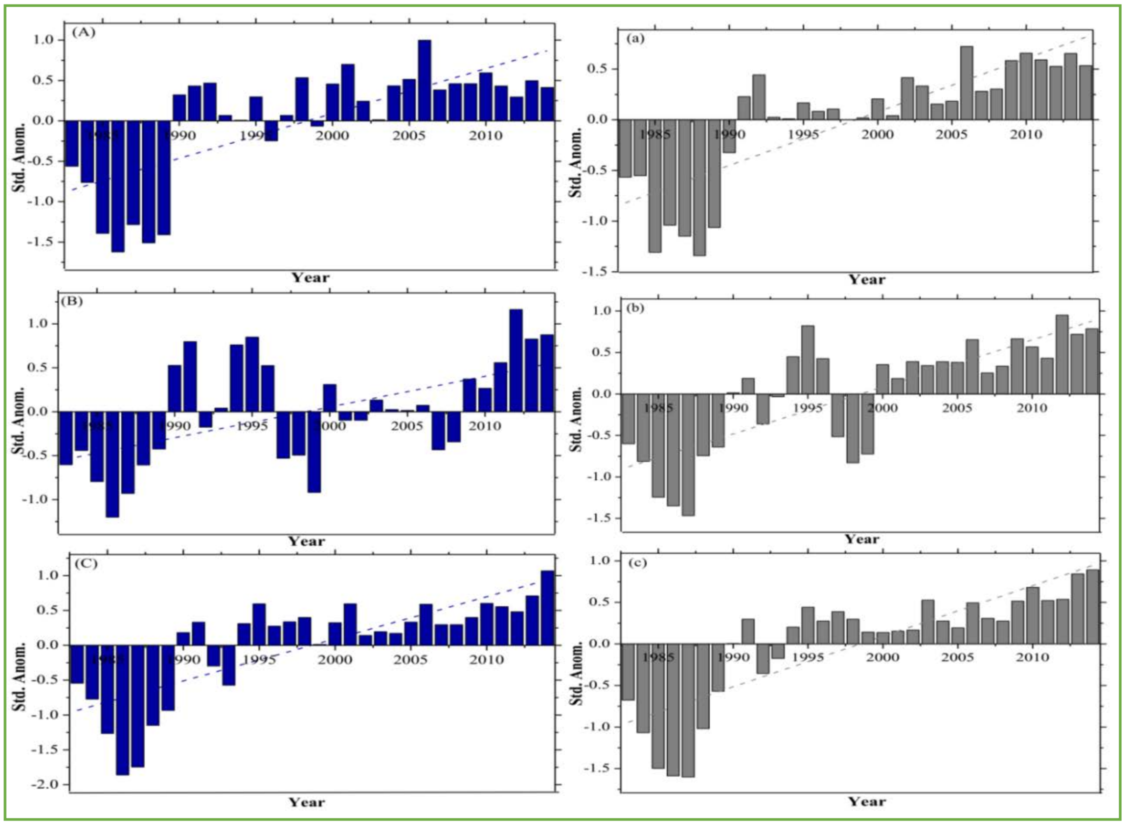

Figure 2.4Standardized anomalies of Warmest night (TNx), over three agro-ecological *Zone*s, (A) Lowland, (B) Midland, (C) Highland (left) and for coldest night (TNn), (a) Lowland, (b) Midland, (c) Highland (right), for the period, 1983-2014

The temperature of the coldest night (TNn) during the observation periods has increased significantly in all AEZs (p<0.001). The magnitude of change in the TNn was reported to be (0.078 °C/year) in the lowland AEZ, (0.075 °C/year) in the midland AEZ, and (0.084 °C/year) in the highland AEZ (p<0.001), respectively.

Similar to the higher magnitude of change observed in the TNx in the highland AEZ, the magnitude of change in TNn is slightly higher than the two AEZs. The anomalies of the TNx and

TNn are shown in Figure 2.4. The TNx's highest positive value was observed in 2006 (Figure 2.4 (A)), in 2012 (Figure 2.4 (B)), and in 2014 (Figure 2.4 (C)) for the lowland, midland and highland AEZs, respectively. On the other hand, the negative anomalies of the TNn were commonly observed in the 1980s across all AEZs while the positive anomalies have been increasing from the 1990s onwards in all AEZs (Figure 2.4 (a)) to Figure 2.4 (c)).

Warm spell duration indicator (WSDI) and cold spell duration indicator (CSDI)

The warm spell duration indicator (WSDI) index which represents the number of days contributing to a warm period was statistically insignificant in all AEZs. However, a significantly decreasing trend was observed in cold spell duration indicator (CSDI) in all AEZs. The CSDI values show a decrease of (0.667 days/year) in the lowland AEZ, (2.259 days/year) in the midland AEZ, and (1 day/year) in highland AEZ Table 2.2.In relative terms, the CSDI is higher in the midland AEZ than in the lowland and highland AEZs. Similar trends were reported by Mekasha*et al*. (2014) for WSDI and CSDI. The CSDI revealed significantly decreasing trend in all AEZs, suggesting that the AEZs are getting warmer although WSDI is not statistically significant in the same AEZs. The decrease in CSDI is in agreement with the observed warming in other studies such as Donat *et al*. (2013), in a study carried out across the globe. However, the recent trends for CSDI and WSDI were mixed in the Upper Blue Nile Basin (Worku*et al*., 2018), which also suggests contextual differences between the current and previous studies.

Diurnal temperature range (DTR)

With regards to the trend in the DTR, all AEZs have experienced significantly decreasing trend (Table 2.2). The magnitude of change of DTR was (-0.052 °C/year) and (-0.043 °C/year) ($p<0.05$) in the lowland and highland AEZs, respectively. A very significant decreasing trend in the DTR of the midland AEZ was observed (0.053 °C/year) ($p<0.001$) (Figure 2.5 (B)). Similarly, Mekasha*et al*. (2014) reported a significantly decreasing trend in DTR only in Negele Borena station in Ethiopia. Moreover, Zhou*et al*. (2009) documented that there has been a decreasing trend in DTR in some other parts of the world, mainly in arid and semiarid regions.

Concurring to this, the mean annual DTR exhibited a reduction by 0.5 to 1°C in Sudan and Ethiopia between the 1950s and 2000 (Hulme, 2001).

A decrease in DTR suggests that the trend in the daily maximum temperature is smaller than the trend in the daily minimum temperature. Earlier studies reported on the relevance of DTR as one of the proxy indicators for climate change. For example, a study by Makowski, Wild, and Ohmura (2008) considered DTR as the important indicator of climate change.

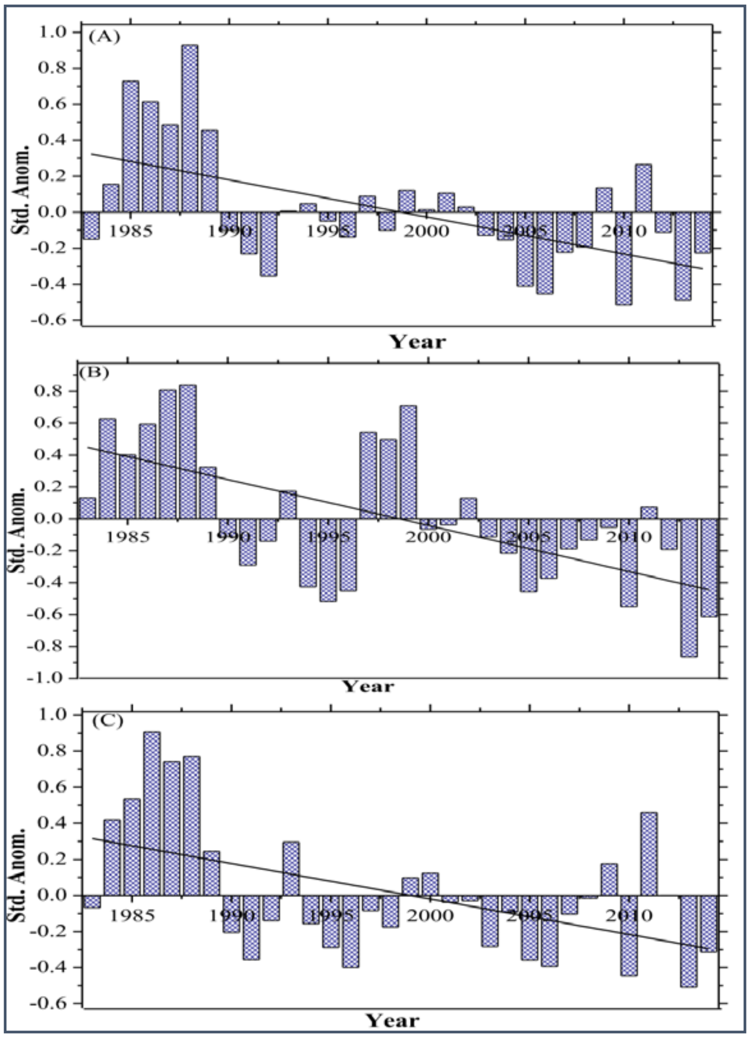

Figure 2.5Standardized anomalies of diurnal temperature range (DTR) (DTR**),** over three agro-ecological *Zone*s, (A) Lowland, (B) Midland, (C) Highland, for the period, 1983-2014

2.3.2 Trends in precipitation extremes

Simple daily intensity index (SDII), consecutive dry days (CDD) and consecutive wet days (CWD)

The SDII, which monitors precipitation intensity on wet days, did not show any significant trend in all AEZs, a finding that is in line with results from (Seleshi &Camberlin, 2006;Jury &Funk, 2013; Worku *et al*., 2018). The highest SDII was recorded in 2013 in the lowland (Figure 2.6 (A)), in 2012 in the midland (Figure 2.6 (B)), and in 2005 in the highland AEZ (Figure 2.6 (C)), respectively. By the same token, the trend analysis of both consecutive dry days (CDD) and consecutive wet days (CWD) imply that the results were not significant in all AEZs (Table 2.3).

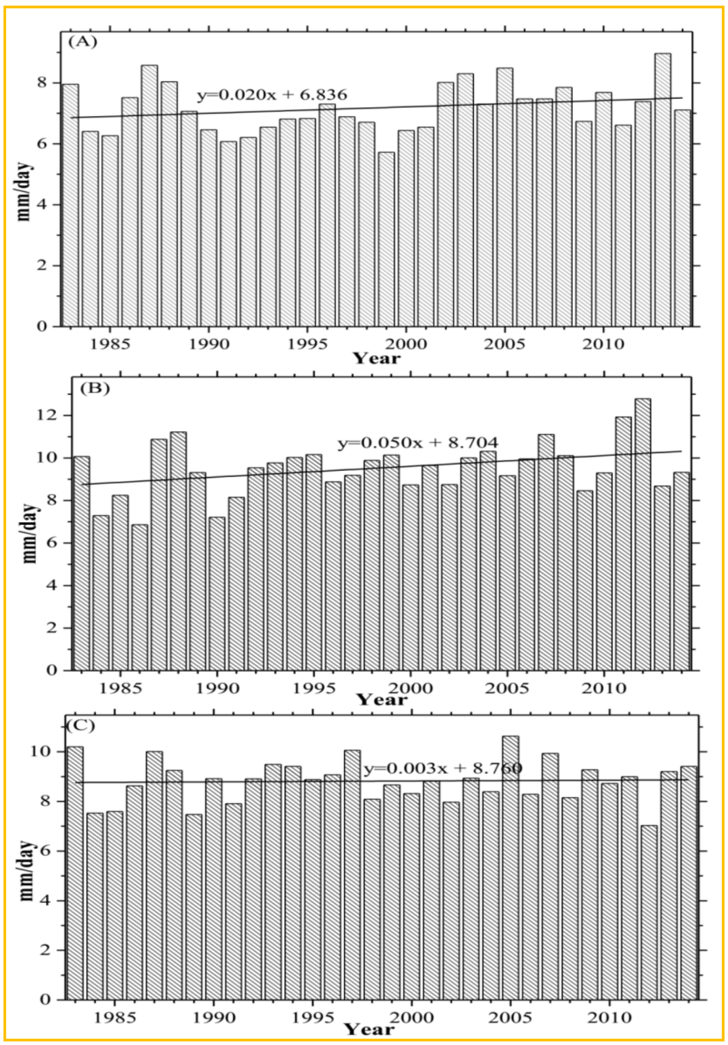

Figure 2.6Trend of the simple daily intensity index (SDII), over three agro-ecological *Zone*s, (A) Lowland, (B) Midland, (C) Highland, for the period, 1983-2014

Table 2.3Trends in precipitation extreme indices per year by AEZ

		Lowland AEZ		Midland AEZ		Highland AEZ	
Index	Units	MK_Z(direction)	Sen's slope	MK_Z(direction)	Sen's slope	MK_Z(direction)	Sen's slope
SDII	mm/day	↑(0.190)	0.026	↑(0.185)	0.044	↑(0.044)	0.006
CDD	Days	↓(-0.085)	-0.396	↓(-0.028)	-0.089	↑(0.020)	0.118
CWD	Days	↓(-0.124)	-0.049	↓(-0.103)	-0.04	↓(-0.159)	-0.017
R10mm	Days	↓(-0.045)	-0.057	↑(0.053)	0.137	↓(-0.060)	-0.041
R20mm	Days	↑(0.198)	0.078	↑(0.331)*	0.325 *****	↑(0.010)	0.00
RX1day	mm	↑(0.171)	0.143	↑(0.059)	0.092	↑(0.295)*	0.297 *
RX5day	mm	↑(0.067)	0.111	↑(0.175)	0.728	↓(-0.067)	-0.143
R95p	mm	↑(0.188)	2.418	↑(0.275)*	6.048 *	↑(0.244)	2.757 *
R99p	mm	↑(0.188)	0.00	↑(0.052)	0.00	↑(0.201)	0.125

*** $p \leq 0.001$; ** $p \leq 0.01$; *$p \leq 0.05$. Note: ↑ (increasing trend)and ↓ (decreasing trend)

The highest CDD was observed in 2012 in the lowland (Figure 2.7 (A)), in 2008 in midland (Figure 2.7 (B)), and in 2000 in highland AEZ (Figure 2.7 (C)), respectively. On the other hand, the highest CWD was observed in the years between 1988 and 1997 in the lowland (Figure 2.7 (a)), in 1992 in the midland (Figure 2.7 (b)), and in 1987 in the highland AEZ (Figure 2.7 (c)), respectively.

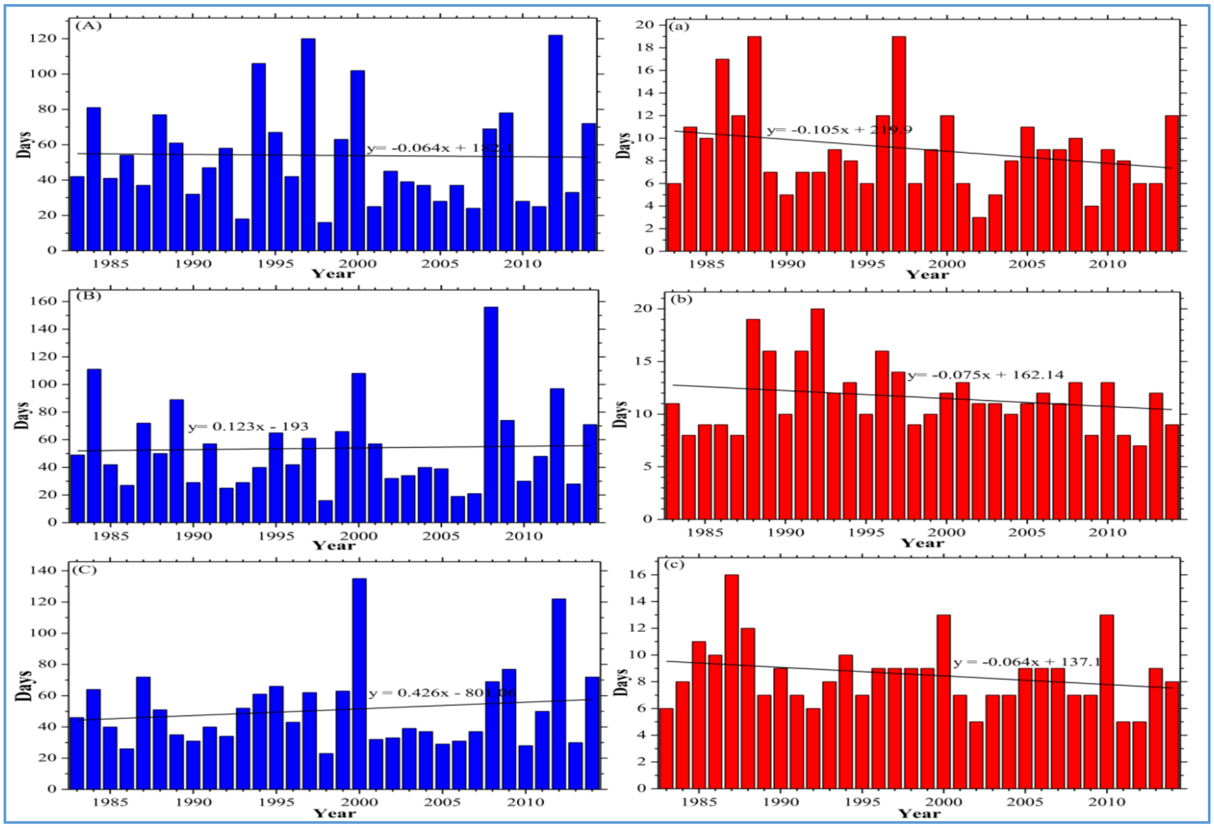

Figure 2.7Trend of Consecutive Dry Days (CDD), over three agro-ecological *Zone*s, (A) Lowland, (B) Midland, (C) Highland (left) and for Consecutive Wet Days (CWD), (a) Lowland, (b) Midland, (c) Highland for the period, 1983-2014

Although insignificant trends were observed in the CDD and CWD, the early 1990s were wet years compared to the 2000s, which signify warming over the studied AEZs. The same trend was documented by previous studies such as (Seleshi &Camberlin, 2006; Jury &Funk, 2013; Worku *et al*., 2018). However, Mekasha *et al*. (2014) observed a decreasing trend for CDD in one station. A study by Mengistu*et al*. (2014) reported that agro-ecological *Zone*s in the Upper Blue Nile River Basin experienced relatively cold years in the 1980s and warm years from the early 1990s to the 2000s.

Number of heavy (R10mm) and very heavy (R20 mm) precipitation days

The number of very heavy precipitation days (R20mm) was increasing with a magnitude of (0.325 days/year) ($p<0.05$) in the midland AEZ but was insignificant in the other AEZs. The highest R20 mm was recorded in the year 2013 in the lowland (Figure 2.8 (a)), in 2012 in the midland (Figure 2.8 (b)), and in 1988 in the highland AEZ (Figure 2.8 (c)), respectively.

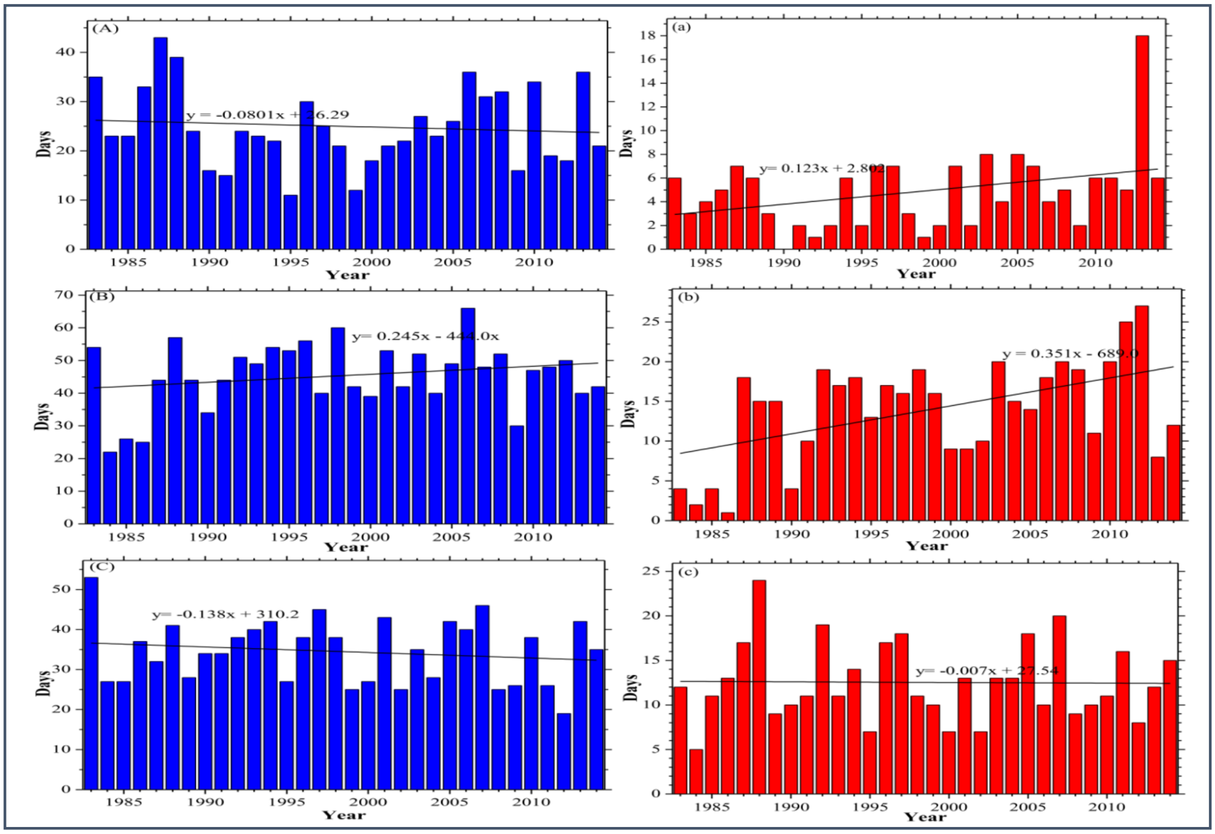

Figure 2.8Trends of number of heavy precipitation days (R10mm) over three agro-ecological *Zone*s, (A) Lowland, (B) Midland, (C) Highland (left) and for number of very heavy precipitation days (R20mm), (a) Lowland, (b) Midland, (c) Highland (right), for the period, 1983-2014

The increasing trend in the rainfall amount in the midland AEZ was in line with recent findings from Degefu and Bewket (2014) in which Wolaita Sodo, as one of the meteorological stations, was found to experience an increasing trend in the average annual total rainfall ($p<0.01$). Similarly, a recent study by Weldegerima, Zeleke, Birhanu, Zaitchik, and Fetene (2018) in Northern Ethiopia have documented an increase in annual rainfall with the magnitude of change being 2.20, 3.42, 6.58, and 2.88 mm/year, in Bahir Dar, Dangila, Debre Tabor, and Gondar, respectively. On the other hand, insignificant decreasing trend was reported both in the lowland and in the highland AEZ in R10 mm while it was insignificant increasing trend in the midland AEZ. The highest R10 mm were recorded in the year 1987 in the lowland (Figure 2.8 (A)), in 2006 in the midland (Figure 2.8 (B)), and in 2007 in the highland AEZ (Figure 2.8 (C)), respectively. In general, the midland AEZ shows both significant and insignificant increasing trends in the R20 mm and R10mm between 1983 and 2014. The variations in the years of highest R10 mm and R20 mm suggest the trend differences between and among the AEZs.

Maximum 1-day (RX1day) and 5-day (RX5day) precipitations

The trend of maximum 1-day precipitation amount (RX1day) was observed to increase in the highland AEZ with a magnitude of (0.297 mm/year) ($p<0.05$). On the other hand, both the lowland and midland AEZs have experienced insignificant trend in the RX1day**.** The maximum RX1day was recorded in the year 2005 in the lowland (Figure 2.9 (A)), in 1988 in the midland (Figure 2.9 (B)), and in 2014 in the highland AEZ (Figure 2.9 (C)), respectively. An insignificant positive trend in RX5day was reported both in the lowland and midland AEZs while it was a negative trend in the highland AEZ (Table 2.3). In relation to the maximum RX5day, it was recorded in 2008 in the lowland (Figure 2.9 (a)), in the years of 1987 and 2007 in the midland (Figure 2.9 (b)), and in 2011 in the highland AEZ (Figure 2.9 (c)), respectively. In summary, with the exception of the highland AEZ for RX1day, all AEZs have experienced insignificant trend both in RX1day and RX5day. On contrary, Worku *et al*. (2018) found out that significant increasing trend was observed in the Rx5day in Fichie and Mendida stations while significant decreasing trend was observed in the Rx1day in Alemketema station in the Upper Blue Nile Basin.

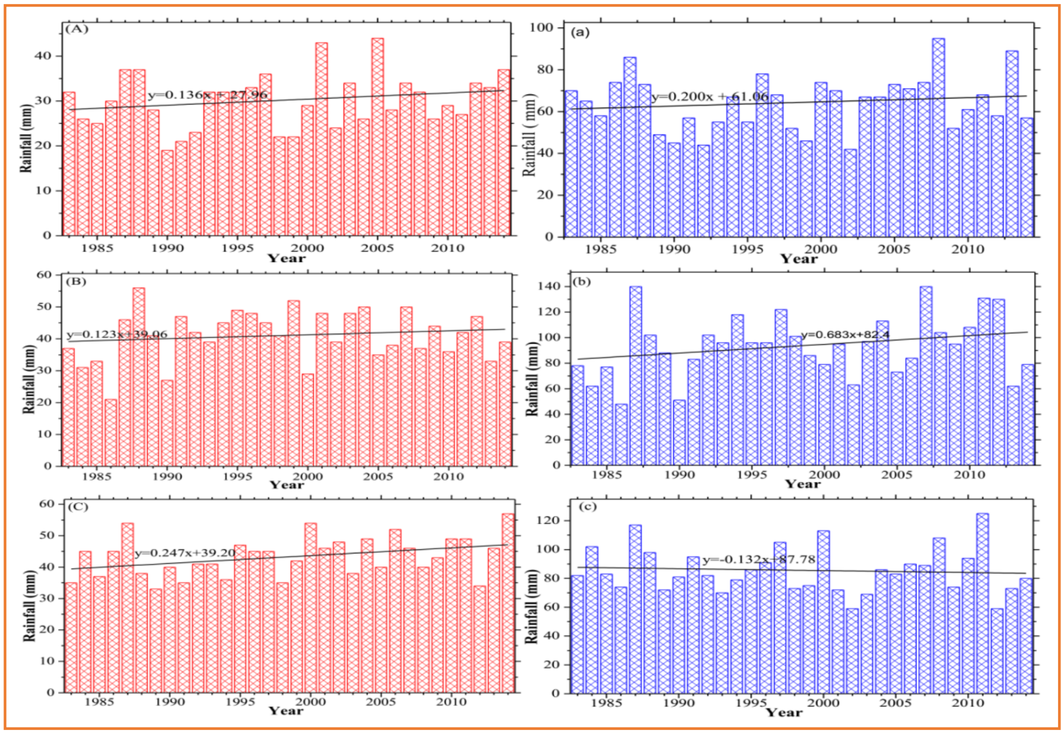

Figure 2.9Trends of Max 1-day precipitation (RX1day), over three agro-ecological *Zone*s, (A) Lowland, (B) Midland, (C) Highland (left) and for Max 5-day precipitation (RX5day), (a) Lowland, (b) Midland, (c) Highland (right), for the period, 1983-2014

2.4Conclusions and recommendations

This study has analyzed changes in the indices of extreme temperature and rainfall based on changes in duration, intensity, and frequency of climatic extremes in the lowland, midland and highland AEZs in Wolaita *Zone*, Southern Ethiopia over the period of 1983–2014. The trend analysis revealed that AEZs have experienced both positive and negative trends in temperature extremes. Overtime, annual maximum value of daily maximum temperature (TXx), annual maximum value of daily minimum temperature (TNx), and annual minimum value of daily minimum temperature (TNn) have shown significant positive trends between 1983 and 2014, except in the midland where TXx deceased by (0.017 °C /year). In terms of AEZ, the magnitude of change in temperature extremes is higher in the highland AEZ but lower in the midland AEZ, implying that the highland AEZ is experiencing a higher magnitude of change in the occurrence of climate extremes. This trend is likely to have adverse effects on the livelihoods of people in the highland agro-ecological *Zone*. The annual number of occurrence of warm nights (TN90p) and the occurrence of warm days (TX90p) show significant warming anomalies for the period between 1983 and 2014 both in the lowland and highland AEZs. The occurrence of warm nights (TN90p) have shown a significant increasing trend ($p<0.001$) in all AEZs except the midland, which shows insignificant increase in TN90p while cool nights (TN10p) were consistently decreasing in all AEZs ($p<0.001$). Insignificant decreasing trend in the frequency of cool days (TX10p) was observed both in the lowland and midland AEZs. TX10p shows a decreasing trend in the highland AEZ ($p<0.05$). The warmest night (TNx) shows a significant increasing trend in all AEZs ($p<0.001$). The magnitude of change in TNx is 0.055 °C, 0.037 °C, and 0.063 °C /year for the lowland, midland, and highland AEZ, respectively. Comparatively, the highland AEZ experienced a higher magnitude of change in the TNx than the midland and lowland AEZs. DTR shows a significant decreasing trend in all AEZs over the study period and indicating warming conditions.

Overall, the trends of warm extremes are increasing and cold extremes are decreasing, implying a significant warming in the AEZs, which is in agreement with results from other studies in different geographic scales. A negative trend in the cold spell duration indicator (CSDI) was observed in all AEZs with magnitudes of change in CSDI being 0.667 days, 2.259 days and 1 days/year for the lowland, midland and highland AEZ, respectively. The trend was significant ($p<0.05$) for both midland and highland AEZs and very significant for the lowland AEZ ($p<0.001$). Even though the trends for consecutive dry days and consecutive wet days were insignificant in all AEZs, the number of very wet days has revealed a positive trend both in the midlands (6.048 days/year) and highlands (2.757 days/year) ($p<0.05$). R20 mm (0.325 days/year) and RX1day (0.297 mm/year) have revealed positive trends in the midland and highland AEZs ($p<0.05$), respectively. In short, most of the precipitation extreme indices have shown insignificant trend across AEZs, signifying no difference was observed between 1983 and 2014.

Generally, the inconsistency of observed patterns in the precipitation extremes and uniformity in temperature extremes reveal that the local level experiences can fit into the meso-macro levels of changes in climate extremes, which in turn can confirm the robustness of extreme indices at different levels of analysis. Therefore, results from extreme event analysis could be crucial information for the design of disaster risk management and development of planned adaptation strategies at local level linking the meso-macro-level evidence in the face of the changing extreme climate events.

Chapter three

3 Climate variability and farmers' perception in Southern Ethiopia

Abstract

The study aims to analyze climate variability and farmers' perception in Southern Ethiopia. A gridded annual temperature and precipitation data were obtained from the National Meteorological Agency of Ethiopia between 1983 and 2014. Using a multi-stage sampling technique, 403 farm households were surveyed to substantiate farmers' perceptions about climate variability and change. The study applied a Non-Parametric-Sen's slope estimator and Mann–Kendall's trend tests to detect the magnitude and statistical significance of climate variability and binary logit regression model to find factors influencing farm households' perceptions about climate variability over three agro-ecological *Zone*s. The trend analysis reveals that positive trends were observed in the annual maximum temperature, 0.02°C/year ($p<0.01$) in the lowland and 0.04°C/year ($p<0.01$) in the highland agro-ecological *Zone*s. The positive trend in annual minimum temperature was consistent in all agro-ecological *Zone*s and significant ($p<0.01$). An upward trend in the annual total rainfall (10 mm/year) ($p<0.05$) was recorded in the midland agro-ecology. Over 60 % of farmers have perceived increasing temperature and decreasing rainfall in all agro-ecological *zone*s. However, farmers' perception about rainfall in the midland agro-ecology contradicts with meteorological analysis. Results from the binary logit model inform that farmers' climate change perceptions are significantly influenced by their access to climate and market information, agro-ecology, education, agricultural input, and village market distance. Based on these results, it is recommended to enhance farm households' capacity by providing timely weather and climate information along with institutional actions such as agricultural extension services.

Keywords: Temperature, Rainfall, Perception, Logit model, Ethiopia.

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3.1 Introduction

The global average temperature has increased by 0.78 °C between 1850 and 2012 (IPCC, 2013) noted the projected increase will range from 1.5°C to 2°C towards the end of the 21st century. Many scholars have produced evidence of global climate change and their projections show that the rate of change will likely increase (IPCC, 2007; Eshetu *et al*., 2014; IPCC, 2014). The case in Africa will be more pronounced than the global average, suggesting warming in all seasons (IPCC, 2013). Most regional studies use long-term changes in rainfall and temperature patterns as a proxy indicator of climate change.

East Africa region is not an exception. Studies have reported high variability in rainfall and the associated adverse effects of rainfall changes in East Africa (Viste *et al*., 2013; Ongoma &Chen, 2017; Ongoma *et al*., 2018a). The impact is primarily associated with higher instability in the inter-annual rainfall primarily affecting rainfall fed livelihood groups (Kassie *et al*., 2014).

Various studies have investigated historical trends of climate variability and change in Ethiopia. For instance, a 0.2°C to 0.28°C rise per decade in the average annual maximum temperature between 1960 and 2006 was reported in recent studies (Keller, 2009; Eshetu *et al*., 2014). Whereas, 0.37 °C/decade increase was observed in the minimum temperature between 1951 and 2006 (McSweeney *et al*., 2008). A projection suggests that Ethiopia will experience a 1.7-2.1ºC increase in the mean temperature by 2050 (EPA, 2012).

As Niles, Lubell, and Brown (2015) pointed out, special attention should be paid to assessing farmers' climate change perception as it requires continued data collection from different contexts and dissemination of new knowledge due to the complex and dynamic nature of climate change (Vermeulen, 2014). Moreover, Broomell, Budescu, and Por (2015) noted that perceived personal experiences can affect climate change belief and the corresponding adaptation and mitigation measures to be taken.

Some attempts have been made on the climate trend analysis in Ethiopia, reporting mixed findings. For example, an insignificant trend was reported on the annual rainfall amount in the Nile basin (Tekleab, Mohamed, & Uhlenbrook, 2013; Gebremicael, Mohamed, Betrie, van der Zaag, & Teferi, 2013; Mengistu *et al*., 2014; Onyutha &Willems, 2015; Teferi *et al*., 2015; Gedefaw *et al*., 2018; Weldegerima *et al*., 2018). Similarly, a non-significant trend in annual and seasonal rainfall was reported in Southwestern Ethiopia (Eshetu, Johansson, & Garedew, 2016)and North Ethiopia (Gebremicael, Mohamed, & Hagos, 2017). Other studies show positive trends in air temperature and negative trends in rainfall (Mekasha *et al*., 2014; Weldegebriel &Prowse, 2016; Tadesse, Bekele, & Tesfaye, 2017; Asfaw, Simane, Hassen, & Bantider, 2018). Other studies (Degefu &Bewket, 2014; Wodaje *et al*., 2016; Wodaje, 2017; Esayas, Simane, Teferi, Ongoma, & Tefera, 2018b) observed both increasing and decreasing trends in the climate parameters, including extreme climate in the study area. However, none of the previous studies have linked their climate trend analysis with farmers' perceptions and its influencing factors.

The existing evidence for farmers' perception of climate change suggests that studies are of three types. The first group includes, Deresa *et al*. (2011), Tesso *et al*. (2012b), Addisu, Fissha, Gediff, and Asmelash (2016), and Asrat and Simane (2018) that used Heckman probit selection model to study factors affecting farmers' perception of climate change and their adaptation strategies. The second group comprises of Legesse, Ayele, and Bewket (2013), Debela, Mohammed, Bridle, Corkrey, and McNeil (2015), and Hadgu *et al*. (2015), which applied binary logit/probit and multinomial logit models focusing on factors influencing only adaptation strategies. Finally, Habtemariam *et al*. (2016), and Abrha and Simhadri (2017) used binary logit/probit/recursive bivariate probit model to examine factors impeding households' perception of climate change and their link with meteorological data.

The stated studies scrutinized the trends in rainfall and temperature data at national, regional and local levels. They reported complex patterns in the climate parameters. However, most of the studies emphasized on mean climate trend analysis using either station based or downscaled data. Accessing the latter is difficult in the situation like the study AEZs. Other studies focused on climate change perception with an emphasis on either factors affecting climate change perception, adaptation or both based on household surveys in their respective geographic setting.

Even recent studies in Wolaita and its surroundings by Degefu and Bewket (2014), Wodaje *et al*. (2016), and Bedeke *et al*. (2018) assessed only trends in extreme and mean climate and adaptation strategies to climate change, respectively. Others have examined the link between farmers' perception of climate change and trends of change in the meteorological data using station-based data and household surveys at national and sub-national levels, that cannot capture the case in the study area. Cross-sectional data from farm households located at different AEZs has also been used for exploring factors affecting farmers' perception of climate change and linking recently promoted gridded time series data for analyzing trends in the climate parameters. There is a paucity of studies that use gridded datasets to analyze climate trends relating to the household perception of climate change in Ethiopia.

Understanding the relationship between national and local level climate parameters as and farmers' views is fundamental for drafting development plans and programs, early warning systems and integrated adaptation strategies that fit the local reality. This study contributes to the rapidly advancing climate change and farmers' perception literature by providing empirical evidence of the climate trend analysis, factors affecting perceptions and their correlation with the trend results over AEZs in Southern Ethiopia.In summary, the purpose of this study is to give a better understanding of recent changes and variability in the rainfall and temperature data, and factors affecting farm households' perception of climate variability and change over three AEZs in Wolaita *Zone,* Southern Ethiopia.

3.2 Methodology

3.2.1 Sample size and procedure

Following Esayas *et al*. (2018b), this study is based on a gridded daily (4 km by 4 km spatial resolution) temperature and rainfall data running from 1983 to 2014. The data are a combination of two data sets. First, a station data was used sourced from the National Meteorological Agency (NMA) of Ethiopia. Second, the satellite rainfall and temperature approximations obtained from the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) and the US National Aeronautics and Space Administration (NASA) were used. In other words, the gridded data set integrated quality-controlled station data from the national observation network with locally calibrated satellite-derived data that were used to fill spatial and temporal gaps in the Ethiopian national observations. Data reconstruction was undertaken by the NMA in partnership with International Research Institute for Climate and Society at Columbia University, USA. Whereas, data calibration and validation were carried out by Reading University, UK (Mengistu *et al*., 2014).

Due to high missing values, poor data quality, and measurement errors on the station-based data, the aforementioned gridded data set were used to address the data quality problems. On this account, this study considered three existing stations, which are located over the AEZs using the gridded data set for the purpose of comparison by AEZ, which in turn is assumed to represent each AEZ with the available climate data over the study period (1983-2014). The stations include Bilate (Lowland), Wolaita (Midland), and Boditi School (Highland) (Figure 1.8).The stations were selected purposively as they have long years (over 30 years) of observed temperature and rainfall data. The analysis period, 1983–2014, was chosen due to available data and to explore recent changes in temperature and rainfall, which help to recognize trends and data coverage across the AEZs. The gridded data can be accessed at NMA (www.ethiomet.gov.et/) for the climatic stations located in the AEZs.

In terms of survey design, the study employed a quantitative-dominant, qualitative mixed research design to select farmers for analyzing factors affecting perception of climate variability (CSA, 2016). In selecting representative sample households, this research followed a three-stage sampling procedures. The approach allows taking small sample units from larger ones that offers an equal chance for all the elements chosen (Boansi, Tambo, & Müller, 2017). In the first stage, three districts, including Damote Gale (highland AEZ), Sodo Zuria (midland AEZ), and Duguna Fango (lowland AEZ), were selected purposively (Figure 1.8). The criteria include a district with dominant AEZ, long years of climate data availability (i.e., above 30 years), existence of meteorological stations, and demographic and livelihood conditions. In the second stage, following the characterization of the AEZs by Gecho*et al*. (2014a), list of all villages in the selected AEZs were used to further cluster them into the respective AEZs. Hence, a proportional three highland, five midland, and three lowland villages were selected randomly (Figure 1.8). Lastly, a probability proportional to size sampling technique (CSA, 2016) was applied to select 403 farm household heads in the area of study. The total sample size was calculated using a sample size computation technique that was proposed by Kothari (2004). The study also used a purposive sampling techniqueto identify and undertake 11 focus group discussions (one per village) and 15 key informant interviews (five per district) to gather qualitative information to corporate climate change perceptions, both on temperature and rainfall indicators, and demographic, socio-economic, and contextual factors affecting climate change perception.Instrument validation and piloting was conducted in a nearby non-survey district aimed to check the appropriateness, completeness, and validity of the data collection tools through a household survey for the quantitative data and expert judgment and elders' feedback for the qualitative tools. Scientific jargons, inappropriate variables, and indicators were dropped and corrected accordingly.

3.2.2 Method of data analysis

ClimPACT2 Software in R was used for meteorological data quality control (Alexander *et al*.,2018). It was tested to label potentially wrong values, and to remove them from the analysis. Outliers were detected and rejected for daily maximum and minimum temperatures exceeding ±3 standard deviation. After quality control, the trend was computed for daily maximum, daily minimum, and daily rainfall amount on annual time scale. The parameters for annual timescale include annual maximum temperature (ATmax), annual minimum temperature (ATmin), and annual total rainfall (ATR) using XLSTAT ®16. While the households survey data management and analysis was carried out in CS-pro ®6.3 and Stata®14. To statistically compare variables between perceived and not perceived households, a t-test was employed for interval variables. A thematic analysis, including description and classification of data, and seeing how concepts interconnect was employed for qualitative information (Bazeley, 2009) to explain and triangulate the survey results.

To see the presence of trends in both annual temperature and rainfall data, the study used the non-parametric Mann-Kendall (MK) test statistic (Kendall, 1938; Mann, 1945) and Sen's estimator test (Sen, 1968) as specified by equations 2.1 to 2.5 in section 2.2.2. Rainfall variability was examined using standardized rainfall anomaly (SRA), precipitation concentration index (PCI) and coefficient of variation (CV). The descriptors were computed using equations 3.1 and 3.2. SRA was obtained using equation 3.1(Bewket & Conway, 2007). The SRA features have contributed to its acceptance for drought monitoring while enabling to identify the dry and wet years in the record (Svoboda, Hayes, & Wood, 2012). Therefore, the drought severity is categorized as, extreme drought (SRA< -1.65), severe drought (1.28 > SRA >-1.65), moderate drought (-0.84 > SRA >-1.28), and no drought (SRA >-0.84).

$$SRA = \left(P_t - P_m\right) / \sigma \quad (3.1)$$

Where SRA is Standardized Rainfall Anomaly; P_t is annual rainfall in yeart; P_m is long-term mean annual rainfall for the period 1983-2014; σ is the standard deviation of annual rainfall for the period 1983-2014.

Oliver (1980) recommends the use of PCI to get information about any possible variations in the rainfall distribution over the year. Hence, PCI values interpreted as typical of a uniform monthly rainfall distribution (PCI below 10); seasonality in rainfall distribution (PCI between 11 and 20); a high variability in monthly rainfall amounts (PCI above 20). Using the PCI, data related to the long-term variability in rainfall amount were obtained and computed using equation 3.2 on annual scale, which was applied to examine heterogeneity of annual rainfall equation 3.2;

$$PCI_{annual} = \sum_{i=1}^{12} \rho_i^{\,2} \Big/ \left(\sum_{i=1}^{12} \rho_i\right)^2 * 100 \quad (3.2)$$

Moreover, inter-annual variability of rainfall and temperature for the selected AEZs was determined by CV (i.e., standard deviation divided by the mean of ATmax, ATmin, and ATR), respectively. Z-score was adapted to compute the temperature anomalies, which is commonly used for rainfall anomalies**.**

Binary logit model estimation

Methodologically so far farmers' perception of climate change has been studied in three different ways as discussed under introduction section. Nevertheless, following the assumption of standard logistic probability distribution like the previous studies including, Ndambiri *et al*. (2012), Bryan *et al*. (2013), Amadou, Villamor, Attua, and Traoré (2015), Abrha and Simhadri (2017) and the suggestions made by Gujarati (2009), the study applied binary logit model, mainly to identify factors affecting farmers' perception of climate change over AEZs.

The logit model considers that the outcome variable is dichotomous in nature, which assumes a value of 1 or 0. It also adopts a discrete vector of repressors X, which are assumed to influence the outcome Y. In line with Abid, Scheffran, Schneider, and Elahi (2019), our dependent variable (*i.e., perceive climate change,* Y =1 *or not perceive climate change,* Y =0) was taken as a combination of an increase in temperature being accompanied by a decrease in rainfall, which results in accurate perception coded as 1 "*perceive climate change*" and coded as 0 "*not perceive climate change*". Gujarati (2009) stated that the functional form of logistic model (the log-odds ratio) as stated in equation 3.3:

$$P_i = E\left(Y_i / X_i\right) = \frac{1}{1+e^{-(\beta_o+\beta_1 X_i)}} = \frac{1}{1+e^{-Z_i}} \quad (3.3)$$

Where P_i is the probability of i^{th} household to be in the first category-perceive climate change, which ranges from 0 to 1; Z_i *i*s a functional form of m explanatory variables (X), which is stated in equation 3.4 as;

$$Z_i = \beta_o + \sum_{i=1}^{m} \beta_i X_i, 1,2,3 \ldots\ldots\ldots m \quad (3.4)$$

where β_o is an intercept and β_i are slope parameters of the model or slops of the equation. It indicates that how the log-odds are in favor of a given household perceives climate change changes as an independent variable change. If P_i shows the probability of a given household perceives climate change and then $1-P_i$ shows the probability of a given household is not perceiving climate change, which is expressed in equation 3.5:

$$1-P_i = \frac{1}{1+e^{Z_i}} \quad (3.5)$$

When equation 3.3 is divided by equation 3.5, the simplified form is stated as equation 3.6:

$$e^{Z_i} = \frac{P_i}{1-P_i} = \frac{1+e^{Z_i}}{1+e^{-Z_i}} \quad (3.6)$$

It explains a ratio of the probability that a household perceives climate change in the probability of household does not perceive climate change. Finally, the logit model is obtained by taking the natural log of equation 3.7 as:

$$Z_i = \ln\left(\frac{P_i}{1-P_i}\right) = \beta_O + \beta_i X_i \quad (3.7)$$

Including an error term ε_i into the model is expressed as given in equation 3.8:

$$Z_i = \beta_O + \beta_i X_i + \varepsilon_i \quad (3.8)$$

Thus, it can be noted that the logistic model defined in the equation 3.8 is centered on the logits of Z. On the other hand, the estimated parameters β_k of the logit model only provide the direction of the effect of the explanatory variables on the binary dependent variable and statistical significance linked with the effect of increasing explanatory variable similar to the Ordinary Least Square coefficients (Peng, Lee, & Ingersoll, 2002). A positive coefficient β_k indicates that the explanatory variable χ_k increases the likelihoodthat $(\gamma_i = 1)$ (*i.e., a farmer perceives the climate change*). However, the coefficient cannot clarify how much the probability of a farmer perceives the climate change $(\gamma_i = 1)$ changes when χ_k changes. In other words, the coefficient β_k does not indicate the magnitude of the effect of a change in explanatory variable χ_k on $\Pr(Y = 1)$ (Abdi *et al.,* 2019). In order to interpret and compute the results, it is relevant to compute the marginal effects using equation 3.9. It describes the effect of a unit change in the explanatory variable on the probability of a dependent variable, i.e., $\Pr(Y = 1)$ (Abdi *et al.*, 2019). Marginal effects can be computed using equation 3.9;

$$\frac{\partial \mathrm{P}_\kappa}{\partial \mathrm{X}_\kappa} = \frac{\beta_\kappa e^{-\mathrm{Z}_\kappa}}{(1+e^{-\mathrm{Z}_\kappa})^{\mathrm{z}}} \quad (3.9)$$

The logit model was regressed on a set of relevant explanatory variables hypothesized based on literature and data availability that are assumed to affect farmers' perception ofclimate variability and change (Table 3.8). Factors included are of two types. The internal factors include, farm-specific socio-economic and demographic variables such as sex, age, education, landholding, age dependency ratio, non-farm participation, food secured months, and household productive assets (Tesso *et al*., 2012b; Legesse *et al*., 2013; Abrha &Simihadar, 2017; Addisu *et al*., 2016; Habtemariam *et al*., 2016; Tadesse *et al*., 2017; Asrat &Simane, 2018).

External factors that affect farmers' perception to climate variability and change comprise, access to the village market, climate information, market information, credit services, trainings, agro-ecology, access to irrigation and agricultural input use (Ndambiri *et al*., 2012; Bryan *et al*., 2013; Addisu *et al*., 2016; Habtemariam *et al*., 2016; Abrha & Simihadar, 2017; Asrat & Simane, 2018; Abid *et al*., 2019). Variables such as total farm size (ha), household productive assets (local currency-*birr*), age dependency ratio (number), distance to the village market (km), age of the farmer (years), and food secured months (number) are continuous variables and measured in the respective unit. While all other variables are dummies and take the value of one and zero (Table 3.8). Using these variables, the empirical specification of the logit model was then equation 3.10;

$$Z_i = \beta_O + \beta_1 \text{age} + \beta_2 land + \beta_3 mard + \beta_4 adr + \beta_5 f\,\text{sec} + \beta_6 asset + \beta_7 sex + \beta_8 edu + \beta_9 cli\,\text{inf}$$
$$+ \beta_{10} mar\,\text{inf} + \beta_{11} nonfarm + \beta_{12} credit + \beta_{13} ae + \beta_{14} input + \beta_{15} train + \beta_{16} irruse + \varepsilon_i \quad (3.10)$$

Where, age (age of the head), land (total land size), mard (distance to village market), adr (dependency ratio), fsec (food secured months), asset (household productive assets), sex (sex of the head), edu (education of the head), cliinf (climate information), marinf (market information), nonfarm (participation in non-farm), credit (access to credit), ae (agro-ecology), input (improved seed), train (received training), and irruse (irrigation use), respectively.

3.3 Results and discussion

3.3.1 Variability and trends in temperature

Variability and trends in annual maximum temperature

The CV of the highland AEZ is nearly double that of the midland and lowland AEZs, suggesting a high variability in the ATmax over the 32 years under study. The year 2012 was observed as the hottest year in AEZs while 1989 was the lowest ATmax year for the midland and lowland AEZs (Table 3.1 and Figure 3.1). The hottest and coldest years are consistent with a study by Mengistu *et al*. (2014), which reported that AEZs in the Upper Nile Basin experienced relatively cold years in the 1980s and warm years from the early 1990s to the 2000s.

Table 3.1 Annual maximum temperature variability by agro-ecological *Zone*s

Station	AEZ	Mean (ºC)	SD	Max (ºC)	Year	Min (ºC)	Year	CV (%)
Bilate	Lowland	27.87	0.45	28.65	2012	26.75	1989	1.62
Wolaita	Midland	26.59	0.36	27.59	2012	26.01	1989	1.35
Boditi school	Highland	25.50	0.66	26.76	2012	23.33	2006	2.59

Table 3.2 and Figure 3.1show the temporal and spatial variability and trend of ATmax in the AEZs. It exhibited, an upward trend of 0.02 °C/year ($p<0.01$), signifying 0.64 °C increase between 1983 and 2014 in the lowland AEZ. The highland AEZ experienced significantly increased temperature in the ATmax. The rate of change in the ATmax was 0.04°C/year

($p<0.01$). However, the result for midland AEZ reveals an insignificant downward trend in the ATmax (0.01°C/year) (Table 3.2).

Table 3.2Trend statistics of annual maximum temperature by AEZs (1983-2014)

Station	AEZ	MK_Z (direction)	Sen's Slope (ºC/year)
Bilate	Lowland	↑(0.35)***	0.02***
Wolaita	Midland	↓(-0.11)	-0.01
Boditi school	Highland	↑(0.46)***	0.04 ***

*** Significant at $p<0.01$; ** Significant at $p<0.05$; * Significant at $p<0.1$ level. Note: ↑ (increasing trend)and ↓ (decreasing trend)

In terms of AEZs, the highland AEZ experienced 1.28 °C change ($p<0.01$) compared to the lowland AEZ that exhibited 0.64°C increase ($p<0.01$), notifying highly rapid rate of change in the ATmax over three decades. The warming trend observed in the study area is relatively higher than the historical trend reported at national and sub-national levels. For instance, a warming trend of 0.1 °C/decade in Ethiopia between 1953 and 1999 (NMA, 2007) while it was 0.2 °C/decade for Addis Ababa from 1951 to 2002 (Conway, Mould, & Bewket, 2004).

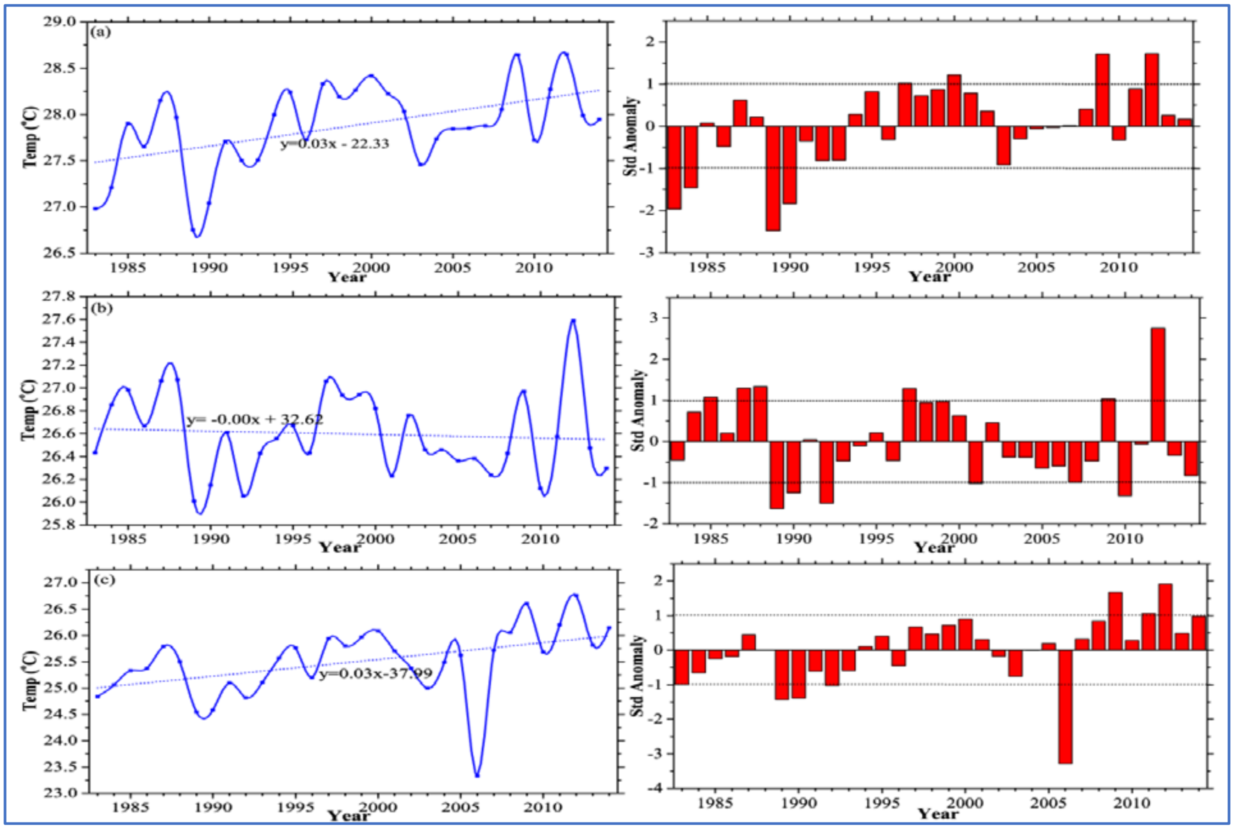

Figure 3.1 Spatial and temporal variations in the annual mean maximum temperature over the three agro-ecological *Zone*s, (a) Lowland, (b) Midland, (c) Highland, for the period, 1983-2014: trends (left) and anomalies (right)

The inter-annual variability of the ATmax presented in (Figure 3.1) indicates that the AEZs have experienced both warm and cool years during the 32 years. Therefore, the anomaly detected was complex for midland AEZ.A warming trend in lowland and highland AEZs was reported, informing the recent years are warmer than the earlier years. Even though the magnitude in the ATmax differs, the general warming trend matches with studies reported both at national level (NMA, 2007) and local level (Tesso*et al*., 2012b; Mengistu *et al*., 2014).

Several other studies at various spatial and temporal scales have recognized warming trends in maximum temperature (Eshetu *et al*., 2014; Degefu & Bewket, 2014; Gedefaw *et al*., 2018; Weldegerima *et al*., 2018; Worku *et al*., 2018). On the rate of increase, without adaptation, more than 1°C warming has adverse impacts (IPCC, 2014). In this case, the trend analysis over three decades suggests that the highland AEZ has exhibited warming of 1.28 °C while the lowland experienced 0.64 °C increase, implying some possible negative impacts on the lives and livelihoods of smallholder farmers mainly in the highland AEZ. Relating rapid change in the climate, the shifting nature of the AEZ and its contributing factors, farmers in the highland AEZ stated:

> *"Previously, there were big trees that used to pull down rain and cold air. Today, these trees are not there due to high deforestation and expansion of farmland. These trees have been cleared and the land is open for wind. Rather, the lands are covered by eucalyptus, which does not maintain soil fertility. Because of the change in climate, we are not sowing crops during the same time as we used to do before. The farm calendar of both cultivation and harvesting has changed over time. This was a highland before as cold as Damota-highest point. It is like a lowland now. We have thus suffered from high temperatures day in and day out."* [Discussions in Highland AEZ, March 2017].

Supporting this idea, one of the key informants from the same AEZ shared his experiences:

> "*Malaria was one of the major shocks that claimed the lives of many people before the recent expansion of health services in the lowland areas. Currently, with the change of temperature from lowland to highland areas, malaria occurred in areas where there were no incidences before, indicating that the highland AEZ is no longer highland in its main characteristics*." [Key Informant Interview in Highland AEZ, March 2017].

The rapid change in the ATmax reveals the shift in the AEZ where the highland AEZ is changing in its main features and showing somewhat different patterns in the climate components, specifying changes in the climate in the past years in Wolaita.

Variability and trend in annual minimum temperature

The ATmin is 14.80 °C (CV=6.49 %), 14.86 °C (CV=5.10%), and 13.64 °C (CV=7.26 %) for lowland, midland, and highland AEZ, respectively (Table 3-3). It shows relatively high variability in the highland AEZ than the other AEZs. The year 1986 was the coldest year in all

AEZs. The finding agrees with the cold and warm years reported among AEZs of the Upper Nile Basin (Mengistu *et al*., 2014).

Table 3.3Annual minimum temperature variability by Agro-ecological *Zone*s

Station	AEZ	Mean (ºC)	SD	Max (ºC)	Year	Min (ºC)	Year	CV (%)
Bilate	Lowland	14.80	0.96	15.97	2010	12.74	1986	6.49
Wolaita	Midland	14.86	0.76	15.97	2012	12.96	1986	5.10
Boditi school	Highland	13.64	0.99	15.04	2014	11.11	1986	7.26

It is clear that the change in the ATmin both for lowland and midland AEZs was the same (Table 3-3). It accounts for 0.05 °C/year, signifying 1.6 °C increase in the ATmin in lowland and midland AEZs ($p<0.001$) and ($p<0.01$), respectively. The result for highland AEZ was 0.07°C/year ($p<0.01$), suggesting a highly warming trend observed in highland AEZ compared to other AEZs (Table 3.4). For example, Conway *et al*. (2004) observed an increasing trend in ATmin from 1951 to 2002 (0.4 °C/decade) for Addis Ababa; Mengistu *et al*. (2014) found 0.15 °C/decade in the Upper Nile basin; while Tekleab *et al*. (2013) reported significant increases in ATmin at the annual timescale for many stations studied in the Abay basin. Moreover, ATmin increased by about 0.37 °C/decade between 1951 and 2006 (McSweeney *et al*., 2008). Earlier studies have also shown (Omondi *et al*., 2014; Camberlin, 2017) that most parts of the Greater Horn of Africa (GHA), show warming trends, for both ATmax and ATmin. On a global scale, Vose, Easterling, and Gleason, (2005) and Easterling, Byron, Vose, and Stouffer (2006) reported an increase in the annual maximum temperature by 0.15 °C/decade. However, in this study, findings show relatively higher rate of changes in the ATmax and ATmin than was reported by Camberlin (2017) for GHA and other studies at national level (Keller, 2009; Eshetu *et al*., 2014).

Table 3.4Trend statistics of annual minimum temperature by AEZs (1983-2014)

Station	AEZ	MK_Z (direction)	Sen's Slope (ºC/year)
Bilate	Lowland	↑ (0.64)***	0.05***
Wolaita	Midland	↑ (0.44)***	0.05***
Boditi school	Highland	↑ (0.57)***	0.07***

*** Significant at $p<0.01$; ** Significant at $p<0.05$; * Significant at $p<0.1$ level. Note: ↑ (increasing trend)and ↓ (decreasing trend).

The ATmin shows a significantly increasing trend across all AEZs, but the ATmax has revealed both increasing and decreasing trends. The rate of change for ATmin is faster than the ATmax both in time and space. The faster rate of change in the ATmin than the ATmax is in line with trends found by NMA (2007). As suggested by Peterson *et al*. (2002), the changes are attributed to the decreasing night-time cooling. McSweeney *et al*. (2008) thus indicated that at national level, the average number of hot nights has increased by 137 whereas the hot days by 73 days per year from 1960 to 2003.

The results in Figure 3.2 affirms that all AEZs have experienced both warm and cool years during three decades. Starting from 1998, a warming trend was observed in all AEZs except in 2006 which was the coldest year both in the midland and highland AEZs. In contrast, the 1980s were the coldest years with the ATmin below the mean across all AEZs, which concur with the observation made by Mengistu *et al*. (2014). Hence, the rapid rate of changes both in the ATmax and ATmin signifies the change in temperature is one of the climate elements in the studied AEZs.

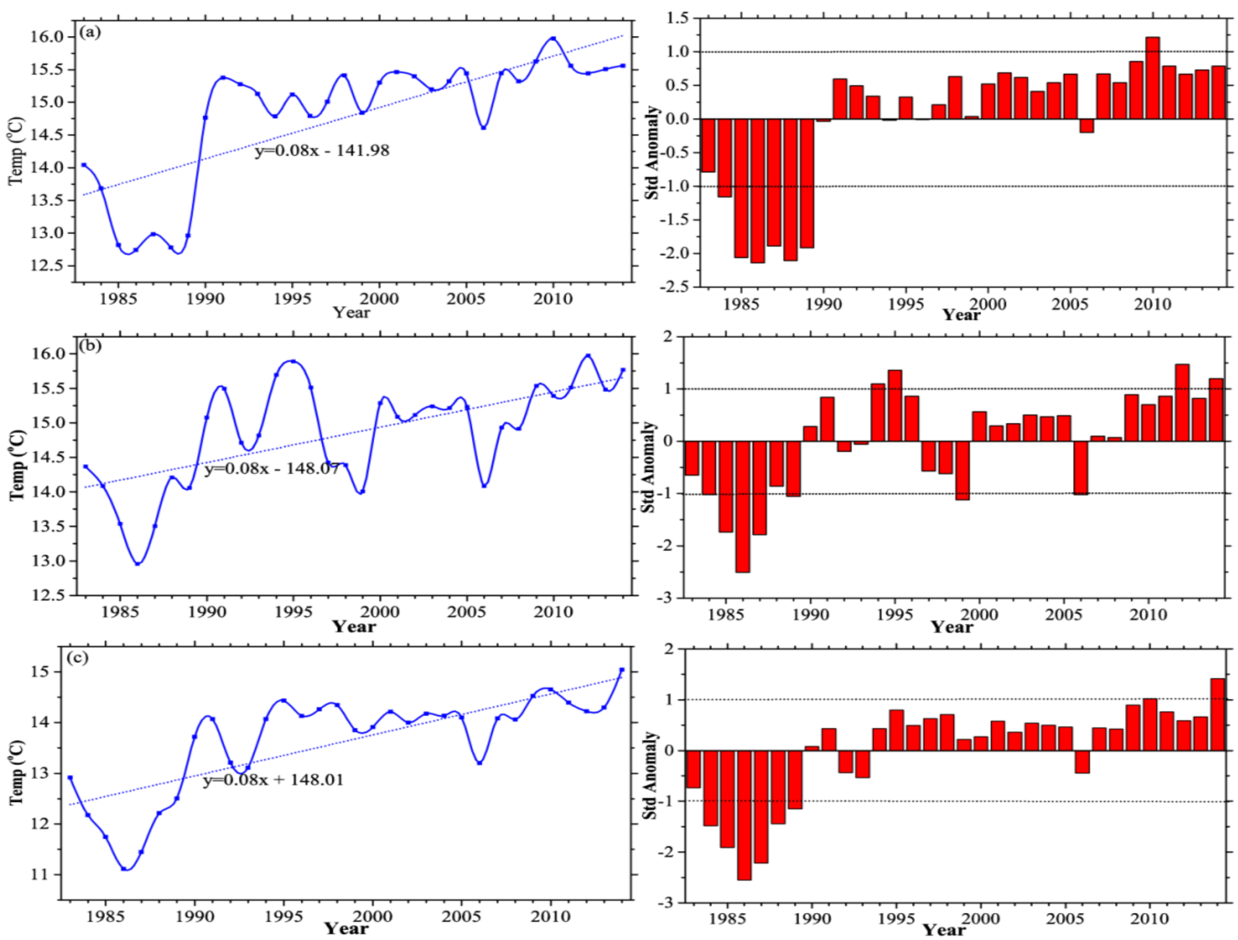

Figure 3.2Spatial and temporal variations in the annual mean minimum temperature over the three agro-ecological *Zone*s, (a) Lowland, (b) Midland, (c) Highland, for the period, 1983-2014: trends (left) and anomalies (right)

3.3.2 Variability and trend in annual rainfall

On annual scale, rainfall is variable in the AEZs (Table 3.5). The ATR in the study AEZs varies from 697 mm in the lowland AEZ to 1,181 mm in the midland AEZ. The CV ranges from 18.57% in the highland AEZ to 25% in the lowland AEZ, suggesting a high rainfall variability in the lowland AEZ while similar patterns being observed in the midland and highland AEZs.

The CV of rainfall exhibits nearly similar patterns, both in the midland and highland AEZs (above 18 %) on an annual scale, whereas the highest CV (25 %) was reported in the lowland AEZ, signifying moderate rainfall variability (Table 3.5). From Table 3.6, similar PCI values were detected in the midland and highland AEZs while lower PCI value was sensed in lowland AEZ, showing irregularity in the rainfall distributions between and among AEZs. On the variability of PCI values, empirical studies reported differently in different contexts. For example, a moderate to high inter-annual rainfall concentration was observed in Amhara region (Ayalew, Tesfaye, Mamo, Yitaferu, & Bayu, 2012) while the same pattern was reported by Kassie (2014) in the Central Rift. In contrast, Hadgu *et al.* (2013) found that high and very high concentrations were observed in the Northern Ethiopia, suggesting poor monthly rainfall distribution.

Table 3.5Annual rainfall variability by agro-ecological *Zone*s

Station	AEZ	Mean (mm)	SD	Max (mm)	Year	Min (mm)	Year	CV (%)	PCI
Bilate	Lowland	696.66	173.47	1064	1987	435	1999	24.90	10.88
Wolaita	Midland	1180.91	223.89	1474	2006	605	1984	18.96	11.38
Boditi school	Highland	881.13	163.64	1252	2007	555	2009	18.57	11.13

Table 3.6 and Figure 3.3 show the trend test results of rainfall on the annual time scale. Though not statistically significant, a decreasing trend was observed (1.80 mm/year) and (0.11 mm/year) in the lowland and highland AEZ, respectively while an increasing trend (10 mm/year) ($p<0.05$) was exhibited in the midland AEZ. The increasing trend in the ATR in the midland AEZ was in line with findings by Degefu and Bewket (2014) and Esayas *et al*. (2018b), in which the midland

AEZ experienced an increasing trend in the ATR. Likewise, Weldegerima *et al*. (2018) reported an increase in ATR in three stations in Northern Ethiopia. To this end, the figures suggest that the ATR trend was neither decreasing nor increasing between 1983 and 2014 in all except the midland AEZ. The findings are consistent with a study in three meteorological stations, including Bilate, which did not show a significant trend in ATR (Wodaje *et al*., 2016). Similarly, the total rainfall trend in the selected AEZs is in agreement with most of the empirical studies in Ethiopia that reported neither decreasing nor increasing patterns of rainfall amounts over time (Tekleab *et al*., 2013; Gebremicael *et al*., 2013; Mengistu *et al*., 2014).

Table 3.6Trends statistics of total rainfall by AEZs (1983-2014)

Station	AEZ	MK_Z (direction	Sen's Slope (mm/year)
Bilate	Lowland	↓(-0.075)	-1.80
Wolaita	Midland	↑(0.274)*	10*
Boditi school	Highland	↓(-0.01)	-0.11

*** Significant at p<0.01; ** Significant at p<0.05; * Significant at p<0.1 level. Note: ↑ (increasing trend)and ↓ (decreasing trend).

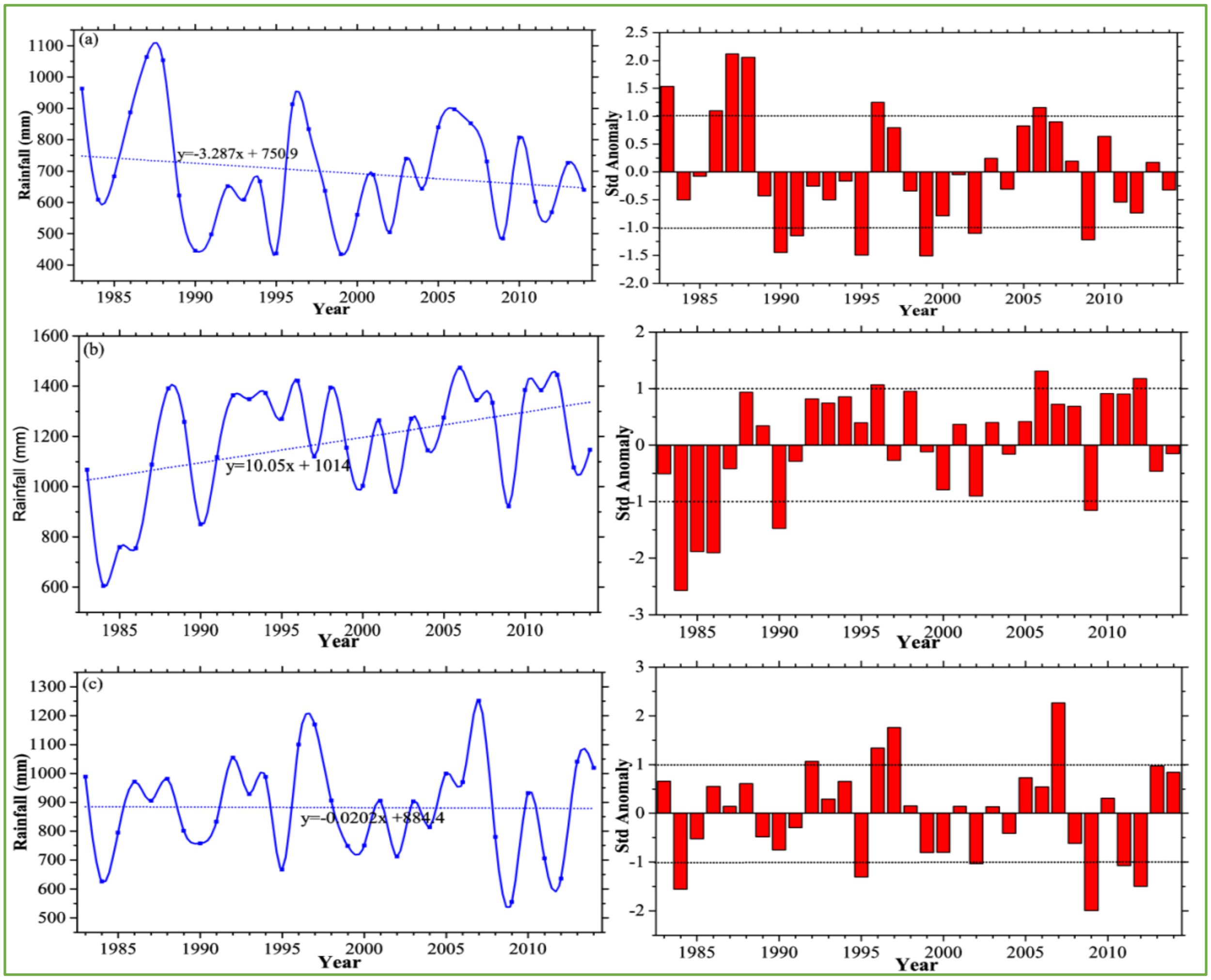

Figure 3.3Annual total rainfall trends over the three agro-ecological *Zone*s, (a) Lowland, (b) Midland, (c) Highland, for the period, 1983-2014

The inter-annual rainfall variability informs that AEZs have experienced negative and positive anomalies in the ATR (Figure 3.3). Hence, 1999, 1984, and 2009 were the driest and 1987, 2006, and 2007 were the wettest years in the lowland, midland and highland AEZ, respectively. Drought categories are summarized in Table 3.7 based on McKee, Doesken, and Kleist (1993) drought classification. As a result, 13 (40.63 %), 10 (31.25%), 4 (12.50%), and 2 (6.25%) were observed as mild drought, normal, moderate drought, and severe drought years in the lowland AEZ, respectively. Only, 2 (6.25 %) was reported as extreme wet years in the lowland AEZ, signifying nearly 60% of observed drought conditions. Likewise, the 1980s were detected as a wet decade in the lowland AEZ (Figure 3.3a). In midland, 17 (53.13 %) were normal years while extreme wet conditions have not been observed at all. In highland, 16 (50 %) was a normal year, whereas 2 (6.26%) were reported as severe wet and extreme wet years. 14 (44 %) were drought years with varying levels of severity (Table 3.7 and Figure 3.3c). One key informant vividly noted the frequent occurrence of drought in the area as follows:

> *"Hitherto, drought occurred at least on a decadal basis, which was the case for the introduction of the bigger non-governmental organizations like World Vision in Wolaita. Its occurrence continuously increased from time to time and begun to happen on a yearly basis. For example, due to El Niño, we faced a drought last year (2016), which affected animals and caused even complete crop failure. There was also the outbreak of pest (virus) that damaged maize. This was a strange phenomenon." [Key informant Interview* in Lowland AEZ, March 2017].

Regardless of these fact, one of the key informant in the midland AEZ stated the limited actions as follows:

> *"There are no proactive measures to undertake before the shock happens. We always react after the shock. Every year, a study is conducted on the level and magnitude of vulnerability to shocks, which is jointly done by a multi-agency team drawn from federal, regional and zonal institutions. But the proactive measures are poor."* [Key informant Interview in Midland AEZ, March 2017*]*.

Table 3.7Standardized rainfall indices over the three agro-ecological *Zone*s, (a) Lowland, (b) Midland, (c) Highland, for the period, 1983-2014

Drought category	SRA ranges	Percentage and frequency of occurrence (Years)							
		Lowland (a)		Midland (b)		Highland (c)		Total (d)	
		N	%	N	%	N	%	N	%
Extreme drought	-2.0 or Less	-	-	1	3.13	-	-	1	1.04
Severe drought	-1.5 to -1.99	2	6.25	2	6.25	3	9.38	7	7.29
Moderate drought	-1.0 to -1.49	4	12.50	2	6.25	3	9.38	9	9.38
Mild drought	-0.99 to 0	13	40.63	10	31.25	8	25	31	32.29
Normal	+ 0.01 to + 1.49	10	31.25	17	53.13	16	50	43	44.79
Severe wet	+1.5 to +1.99	1	3.13	-	-	1	3.13	2	2.08
Extreme wet	+2.0 or more	2	6.25	-	-	1	3.13	3	3.13

In general, 44% were observed as normal years across AEZs while 50 % were drought years (Figure 3.4). The study result is partly agreeing with the national level anomaly trend reported by McSweeney *et al*. (2008). The national worst drought years also fits with realities in the study area. However, the anomaly trend in the study area partly differs with the national level figures when seen from the AEZs perspectives. In the lowland, 1980s was thewettest decade, while it was the 1990s in the midland and partly wettest in the highland in the 2000s (Figure 3.3 and Figure 3.4), respectively. The differences in the anomaly years suggest the high annual rainfall variability among the AEZs.

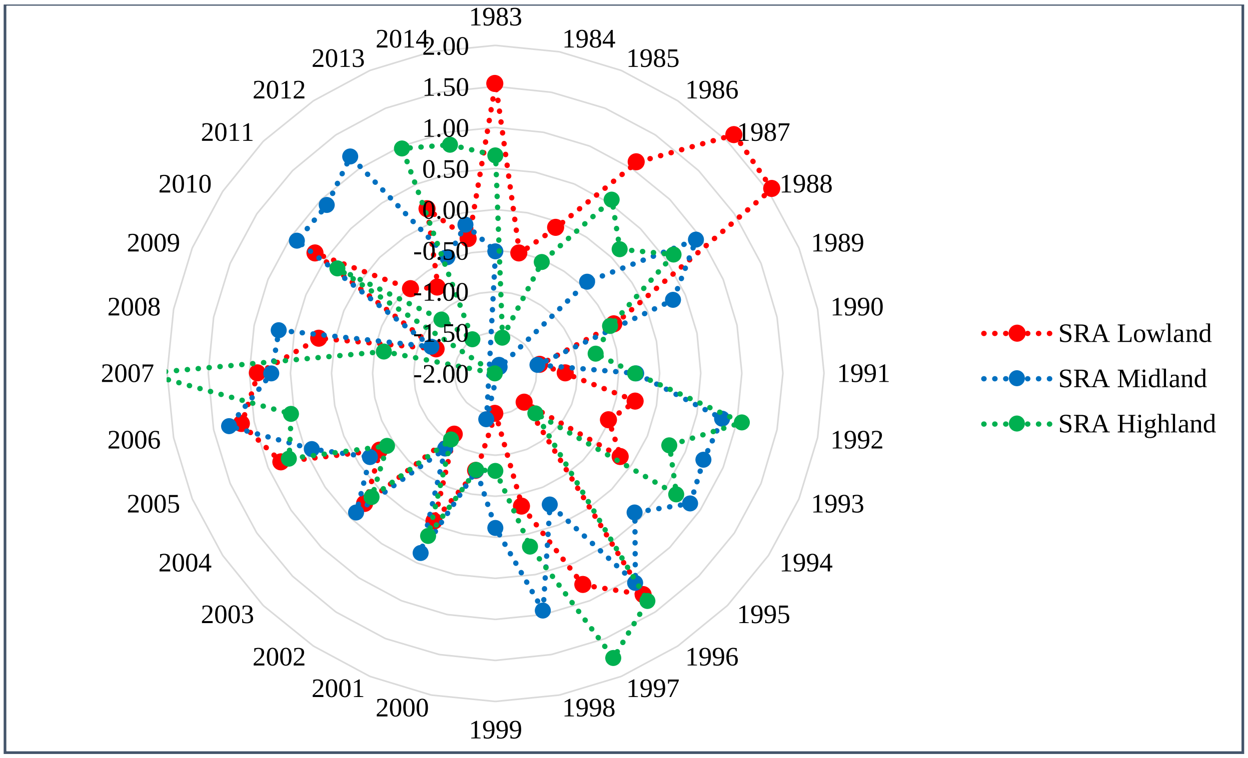

Figure 3.4Drought occurrence years over the period of 1983 to 2014 in the three agro-ecological *zone*s

3.4 Spotting farmers' perception of local climate variability and change

Depending of the research contexts, different studies have been carried out to examine how farmers perceive changes in the climate system. Understanding farmers' perception levels and the various adaptation strategies individual households employ would benefit to gather supplementary information relevant to policy and intervention to tackle the challenges of climate change.

The descriptive analysis show that about 248 (61.54 %) of the farmers perceived changes in the climate parameters (i.e., increased temperature and decreased rainfall) in the aggregate sample. As for AEZ, 61 (67.78 %), 121 (61.11%), and 66 (57.39%) of farmers perceived the changes in highland, midland, and lowland AEZs, respectively (Figure 3.5). This is in agreement with the household perception regarding increased temperature and decreased rainfall reported in Ethiopia and other countries (Deressa *et al*., 2011; Teso *et al*., 2012b; Gebrehiwot & Veen, 2013; Amadou *et al*., 2015; Kibue *et al*., 2016; Habtemariam *et al*., 2016; Weldegebriel & Prowse, 2016; Abrha & Simhadri, 2017; Ayanlade, Radeny, & Morton, 2017; Tadesse *et al*., 2017;Mkonda, He, & Festin, 2018). In our case, the proportion of farmers who perceived increasing temperature and decreasing rainfall is slightly different compared to studies in Ethiopia and other countries, being influenced by factors affecting their level of perception in general and the type of meteorological data (station vs. gridded data), and climate data availability (longer vs. shorter time period) in particular. Moreover, Schwartz (2012) pointed that people believeclimate may change owing to fresh climate experiences, such as the recent 2015/2016 El Niño events prior to the data collection period may contribute to their perception in the study area context.

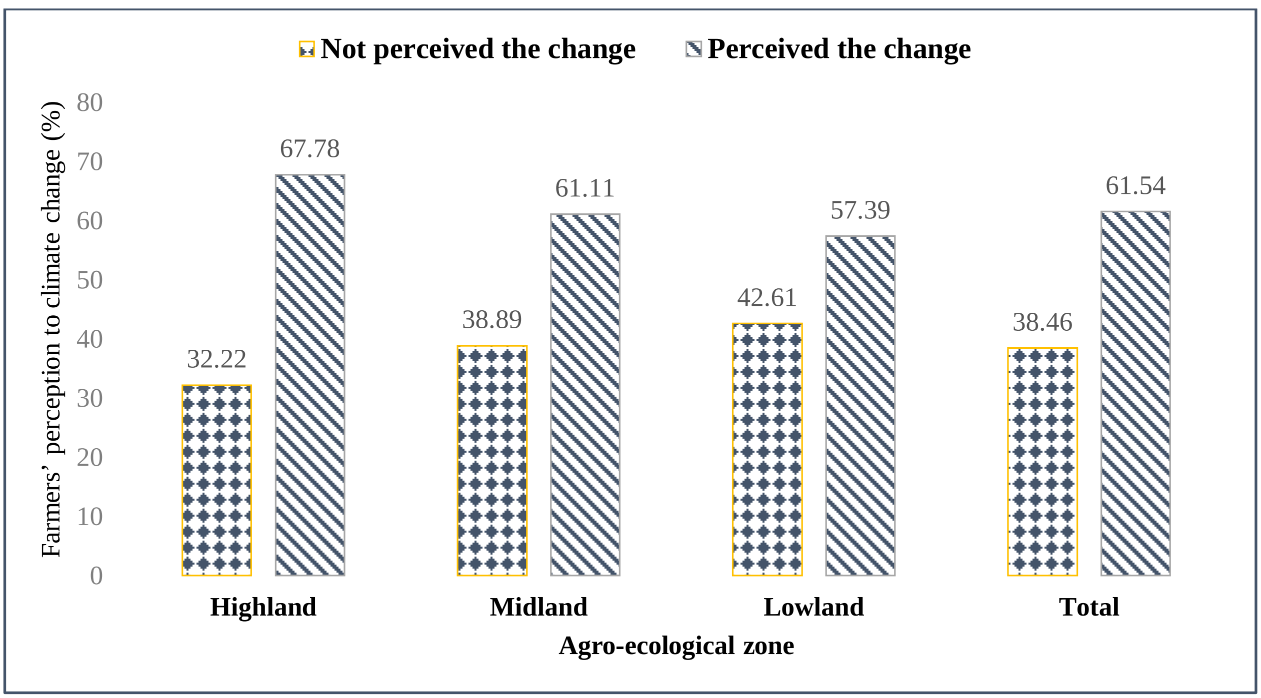

Figure 3.5Farmers perception of climate change

The data on the temperature indicators also revealed that farmers perceived an increase in dry season temperature and hot days' temperature, which are consistently increasing over the AEZs. In addition, over 60% of farmers in the highland AEZ perceived an increase in rainy season temperature while a comparable proportion of farm households perceived increased temperature in the rainy season both in the midland and lowland AEZs (Figure 3.6). The farmers' perception results are in line with a recent study in the same AEZs (Esayas *et al*., 2018b). Others studies observed similar patterns in different parts of Ethiopia (Tesso *et al*., 2012b; Habtemariam *et al*., 2016; Weldegebriel & Prowse, 2016; Abrha & Simhadri, 2017; Tadesse *et al*., 2017; Saguye, 2017).

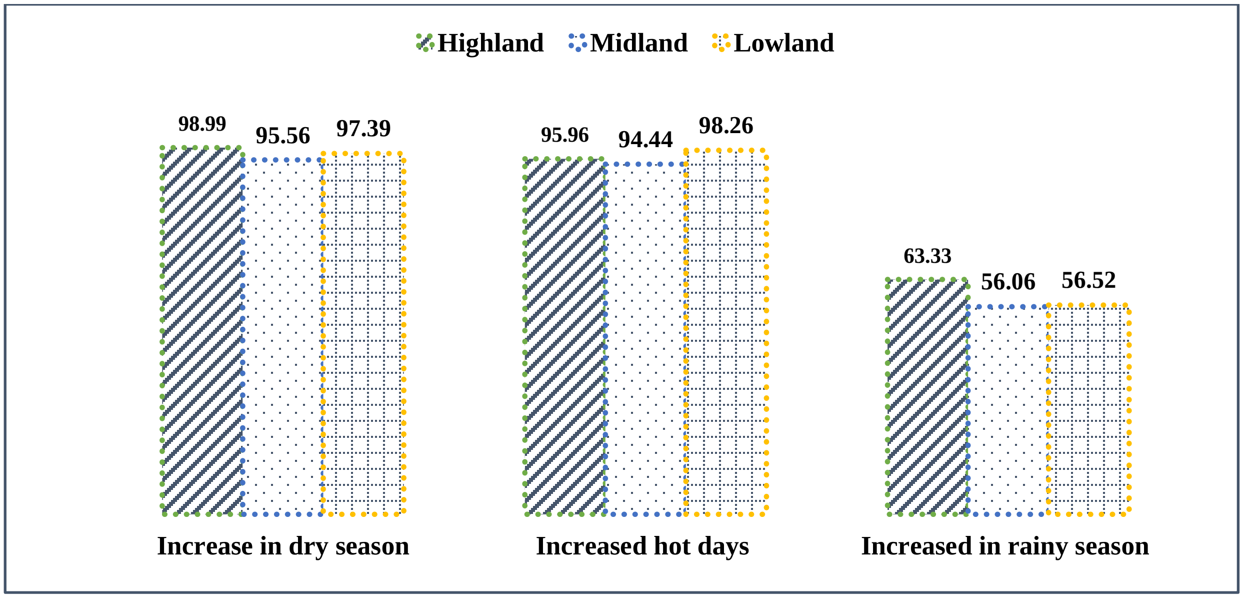

Figure 3.6Farmers perception to temperature indicators

Farmers in all AEZs perceived that rainfall comes late. Farmers in the highland AEZ perceived that the rainfall goes early and observed decreasing trend in the short-rains. In the same AEZ, farmers have better perceived for all rainfall indicators compared to those in the lowland AEZ. In general, farmers in all AEZs perceived declining trends both for the *belg*/short-rains and *Meher*/long-rains over the last two decades, which makes rainfall erratic (Figure 3.7). The result agrees with empirical studies like Tesso *et al*. (2012b), Abrha and Simhadri (2017), Habtemariam *et al*. (2016), Weldegebriel and Prowse (2016), Tadesse *et al*. (2017), which reported that farmers perceived declining trend in the rainfall amount over years in Ethiopia.

Similarly, a study by Mkonda *et al*. (2018) reported that a significant increasing temperature was observed locally in all the AEZs in Tanzania.

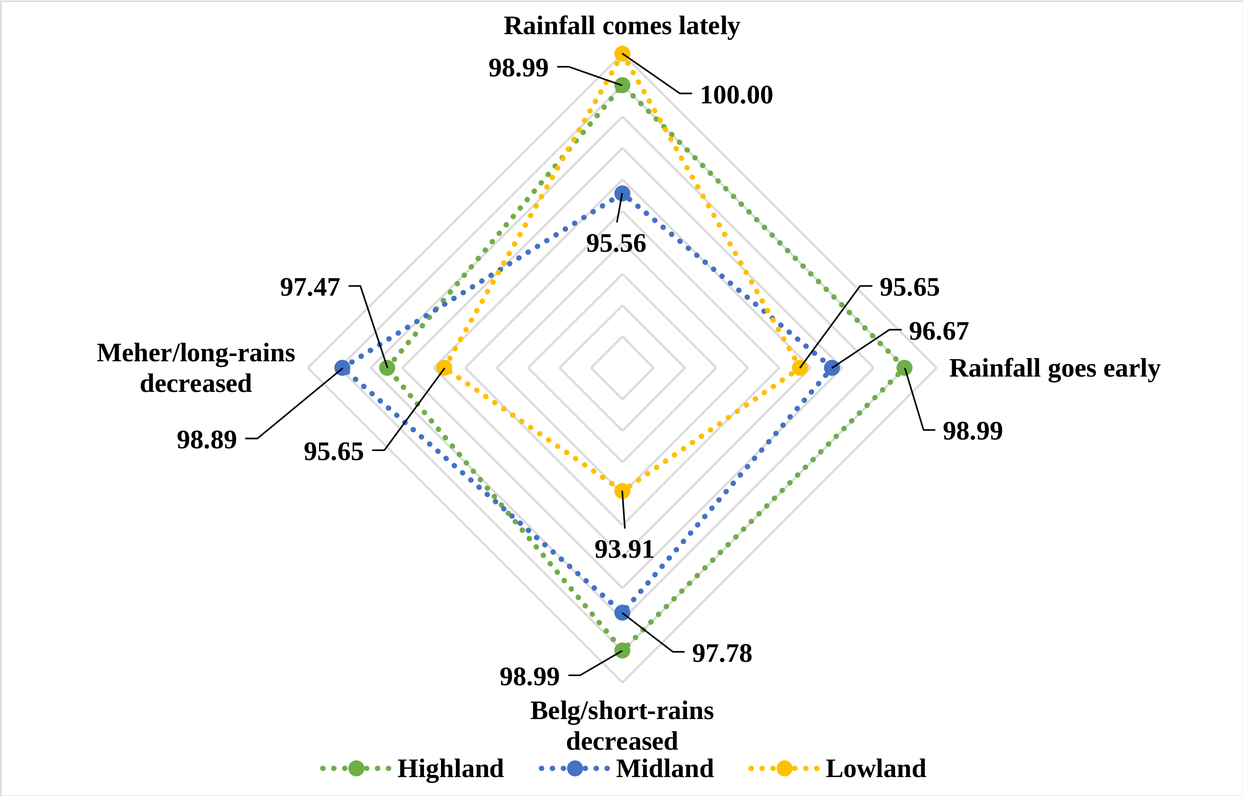

Figure 3.7Farmers perception to precipitation indicators

Regarding the perceived impacts of climate change, farm households witnessed impacts, including, crop productivity decline (98.26%), food price inflation (98.01%), increased frequency of drought (94.79%), increased crop pest (70.72%), increased frequency of floods (68.73%), shortage of water for human use (63.03%), emergence of new pests (61.79%), shortage of water for irrigation (61.04%), increased livestock disease (58.81%), and conflict over diminishing resources (55.83%) in order of severity across AEZs (Figure 3.8). Similarly, Tesso *et al*. (2012b) documented perceived impacts of climate change among AEZs in North Shewa, Ethiopia. Hence, farmers' perception of the climate-induced impacts over years is indicative of Ethiopia's vulnerability to climate variability and change. Thus, studies recognized that Ethiopia suffers from problems associated with high rainfall variability (Degefu *et al*., 2017). Specifically, Amsalu and Alebachew (2009) show that climate change has both direct and indirect impacts on the occurrence and spread of pests and diseases. Moreover, extracts from qualitative information supports the changes in the climate parameters and the corresponding impacts over the last two decades as follows:

> *"Before 1999, the area was very green and we had adequate pasture for the cattle. Now, there is no grass for grazing and there is a movement in search of grass. Since 1999, we have witnessed a decrease in rainfall and an increase in temperature warming. The springs have dried and the vegetation cover has been declining. Where there is irrigation, production of crops is good."* [Discussions in Lowland AEZ, March 2017].

Ethiopia has faced many droughts and floods since 1980 (World Bank, 2010). Since 1900, Ethiopia has confronted 47 major floods that killed nearly 2000 people and affected a population of about 2.2 million (You &Ringler, 2010). It also experienced 12 major droughts between 1900 and 2010 that claimed the lives of over 400,000 people and affected more than 54 million (You & Ringler, 2010). Very recently, the 2015/2016 El Niño-induced drought caused food security affecting an estimated 10.2 million people; one of the most severe on record Food and Agricultural Organization (FAO, 2016a). Therefore, although the farmers' perception of climate change differs in the study AEZs and parts of Ethiopia, farmers' perceptions and the trends in climate change complement each other, showing a warming trend.

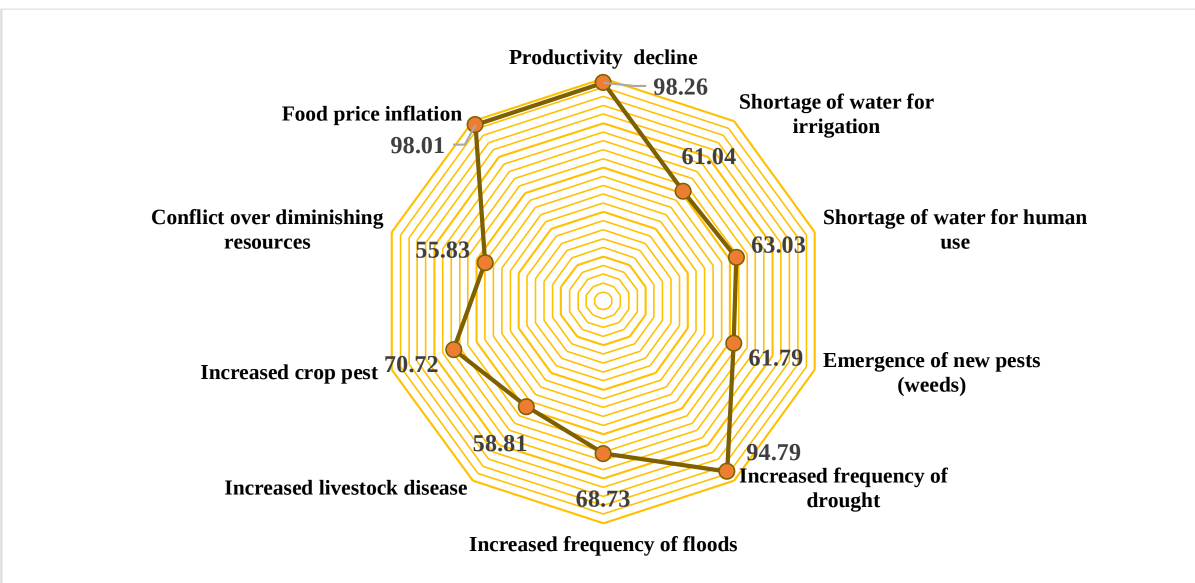

Figure 3.8Perceived impacts of climate variability and change

3.5 Econometric model results

A descriptive statistic of the explanatory variables used is summarized in Table 3.8. The average age was 44.62 year, suggesting that farmers are in the productive age category (16-64 years) (CSA, 2013). The landholding accounts for 0.78 hectare in all AEZs. A statistically significant difference was observed between farmers who perceived climate change (0.71 ha) and not perceived climate change (0.88 ha) ($p<0.1$). The average distance farmers' travel to reach to the village market was 2.87 km. This was statistically significant between the perceived and not perceived farmers, 2.30 km and 3.79 km, respectively ($p<0.05$). Regarding food secured months, farmers in all AEZs were able to feed their families for 7.29 months. A statistically significant difference was exhibited between farmers who perceived climate change (6.89 months) and not perceived climate change (7.92 months) ($p<0.01$), suggesting food secured households are less likely to perceive climate change compared to their counterparts.

Most of the farmers' households were male-headed (65.51 %), with 38.21 % having completed primary school (grade 1 to 8). In terms of access to information, it was evident that 69.48 % had access to climate information and 58.06 % to market information in all AEZs, supporting the positive role of information to farmers' livelihood improvement and preparedness to climate change impacts. Of the sample, 27.05 % of farmers were involved in the non-farm income activities as a way to diversify livelihoods in the face of climate change and enable them to address food and income gaps. The result agrees with Gecho*et al*. (2014a), where they reported 37 % of farmers' derived income from farm and non-farm activities in Wolaita. Only 29.78 % had access to credit, indicating that farm household had limited access to credit services in AEZs. 38.21 % farm households used improved seed in the production seasons, and a negligible percent of farmers had access to irrigation use. Likewise, only 19.85 % of the sampled farmers received trainings important to their livelihood activities across AEZs. The binary logit model was first tested for its suitability and explanatory power for the variables used. In addition, the likelihood function of the binary logit model was significant (Likelihood-ratio (LR), $p<0.01$), signifying its strong explanatory power. The estimated coefficients of the parameters and the marginal effects in the binary logit model ($p<0.1$) for aggregate sample, highland AEZ, midland AEZ, and lowland AEZ are presented in Table 3.8.

Table 3.8 Results of the binary logit model for aggregate sample and agro-ecological *Zones*

			Marginal effect by AEZ			
Continuous explanatory variables	Mean	SD	Aggregate (1)	Highland (2)	Midland (3)	Lowland (4)
Age (years)	44.62	14.06	-0.003 (0.002)	-0.004 (0.005)	-0.003 (0.003)	
Total land size (ha)	0.78	0.79	-0.046 (0.036)		-0.010 (0.078)	-0.081 (0.056)
Distance to village market (km)	2.87	4.98*	-0.019 (0.010)**	-0.030 (0.019)*	-0.011 (0.010)	
Dependency ratio (number)	0.87	0.73	-0.053 (0.038)	-0.107 (0.076)		
Food secured months (number)	7.29	2.85	-0.034 (0.010)***	-0.012 (0.026)	-0.033 (0.015)**	-0.060 (0.021)***
ln (Household productive assets)	6.21	1.10		-0.046 (0.062)		
Discrete Explanatory variables	Count	%	Marginal effect	Marginal effect	Marginal effect	Marginal effect
Sex of HH (1=male)	264	65.51	-0.148 (0.055)***	-0.157 (0.106)	-0.111 (0.082)	-0.276 (0.098)***
Education of HH (1=primary)	154	38.21	0.147 (0.254)***	0.149 (0.106)		0.025 (0.014)*
Climate information (1=yes)	280	69.48	0.264 (0.065)***		0.387 (0.085)***	0.007 (0.125)
Market information (1=yes)	234	58.06	0.137 (0.056)**	0.229 (0.120)*		0.228 (0.107)**
Participation in non-farm (1=yes)	109	27.05	-0.139 (0.064)**	-0.341(0.137)**	-0.096 (0.088)	
Access to credit (1=yes)	120	29.78	-0.041 (0.060)		-0.059 (0.088)	
Agro-ecology (1=lowland)	115	28.54	-0.184 (0.068)***			
Improved seed (1=yes)	154	38.21	0.189 (0.057)***	0.388 (0.096)***		0.208 (0.112)*
Received training (1=yes)	80	19.85	0.220 (0.057)***	0.062 (0.141)	0.257 (0.081)***	
Irrigation use (1=yes)	19	4.71				-0.194 (0.220)
Constant			1.808***	3.945*	1.528**	1.671*
N			403	90	198	115
LR chi^2			85.95	34.16	47.14	28.73
Prob > chi^2			0.001	0.001	0.001	0.001
Pseudo R^2			0.160	0.302	0.178	0.183

Note: Standard errors in parentheses. *** Significant at p<0.01; ** Significant at p<0.05; * Significant at p<0.1 level.

Factors such as agro-ecological *Zone*, sex of the head, non-farm participation, food secured months, and distance to village market are significantly negatively correlated with climate change perception while access to climate and market information, attended training, use of improved seed, and completed primary school are significantly positively associated with climate change perception. Unlike our expectations, farmers who live in the lowland AEZ are less likely to perceive change than farmers who reside both in the midland and highland AEZ. Thus, the probability of perceiving climate change declines by 18.4 % if a farmer, resides in the lowland AEZ ($p<0.01$). This could be due to their inherent vulnerability to impacts of climate change while a small change in the climate parameters in other AEZs is more likely affects the farmers to perceive climate change. In support of this, Ethiopian Panel on Climate Change (EPCC) (2015) has recognized highland areas among the most vulnerable agro-ecology in Ethiopia. Esayas *et al*. (2018b)also reported that the highland AEZ in Wolaita experienced a rapid rate of change in the extreme climate events compared to the lowland AEZ over three decades. Deressa *et al*. (2011) further noted that farmers from the highland AEZ in the Nile basin perceived climate change more than those in the lowland AEZ.

In this study, the sex of the household head is inversely correlated with climate change perception. The probability of male-headed farmers' perception of climate change declines by 14.8 % compared to female-headed households ($p<0.01$). In terms of AEZ, the probability of perceiving the climate change for male-headed households in the lowland AEZ decreases by 27.6 % whereas it is non-significant both in the highland and midland AEZs. This might be because female-headed households are more confined to home the most part of the day and, hence, are more concerned about environmental problems that impede their families and local people (Liu, Smith, & Safi, 2014). Nevertheless, previous studies (Deressa *et al*., 2011; Amadou *et al*., 2015; Habtemariam *et al*., 2016) testified that there was no significant variation between male and female-headed households on the perception of climate change. Hence, sex of the household head is not always positively associated with the perception of climate change. Rather it is a mixed factor depending on the environmental issues studied.

Similarly, participation in non-farm income, food secured months, and distance to village market have negatively influenced farmers' perception of climate change. The probability of perceiving climate change, thus, decreases by 13.9 % when a farm household is involved in non-farm income across AEZs. This could be because non-farm activities are less susceptible to climate change impacts. Ndambiri *et al*. (2012) similarly reported an inverse relationship between participation in off-farm income and perceiving climate change.

The estimated marginal effect for one additional food secured month of the household head decreases the probability of perceiving climate change by 3.4 % ($p<0.01$) for the aggregate sample. The same pattern was observed both in the midland and lowland AEZs, where the probability of perceiving climate change decreases by 3.3 % ($p<0.05$) for midland AEZ and by 6 % for lowland AEZ ($p<0.01$), respectively. This signifies that food secure farm households are less likely to perceive the climate change compared to the food insecure households, since the latter may attribute the food shortage to environmental challenges such as climate change.

The study revealed that there is an inverse relationship between distance to the village market and farmers' perception of climate change. Therefore, one extra km traveled to the village market by the household head decreases the probability of perceiving climate change by 1.9 % ($p<0.05$) for all samples. Farmers residing farther away from the nearest input/output market are less likely to perceive climate change than farmers residing closer to the market. Market outlets offer a crucial linkage for farmers to collect and disseminate information between and among fellow farmers, and the further farmer's distance from such a market linkage, the less likely the farmer would be to perceive climate change. Similarly, a negative influence of distance to village market on the perception of climate change was reported in (Tesso *et al*., 2012b; Abrha &Simhadri, 2017; Asrat & Simane, 2018).

As expected, the logit model shows that there is a positive association between farmers' access to climate information and perception of climate change. Farmers' access to climate information increases the probability of perceiving climate change by 26.4 % in an aggregate sample ($p<0.01$) while it enhances the probability of farmers' perception of climate change by 38.7% ($p<0.01$) in the midland AEZ. Studies also reported that farmers who have better access to climate information are more likely to perceive climate change (Habtemariam *et al*., 2016; Abrha & Simhadri, 2017; Asrat & Simane, 2018). Though farmers recognized these sources of information as vital, they still had their own ways of perceiving climate change (Yaro, 2013).

Likewise, the availability of market information has significant positive correlation with farmers' perception of climate change. Hence, farmers who have access to market information are 13.7 % more likely to perceive the climate change in the aggregate sample ($p<0.05$). In terms of AEZ, the probability of farmers who have access to market information increases the perception to climate change by 22.9 % in the highland AEZ and 22.8 % in the lowland AEZ. This can be attributed to better access to input and output market information. The study shows that farmers using improved seeds are 18.9 % more likely to perceive climate change in the aggregate sample ($p<0.01$), 38.8 % in the highland AEZ ($p<0.01$) and 20.8% in the lowland AEZ ($p<0.10$).

The other variable of interest that influences the probability of farmers' perception of climate change is farmers' education level and received capacity building trainings (proxy variables for level of awareness). The marginal effect revealed that farmers who have completed primary school are 14.7 % more likely to perceive climate change ($p<0.01$) in all samples while the increases was by 2.5 % in the lowland AEZ ($p<0.10$). In this regard, the more educated the household head is, the higher the probability of perceiving the climate change and vice versa. The result agrees with previous studies which reported the positive influence of household education on climate change perception in different contexts (Tesso *et al*., 2012b; Habtemariam *et al*., 2016; Abrha & Simhadri, 2017; Asrat & Simane, 2018). Although small number of farmers have attended capacity building trainings that the results imply that training has a positive influence on farmers' perception of climate change. The computed marginal effect indicates that receiving training increases the probability of perceiving climate change by 22 % for an aggregate sample ($p<0.01$) whereas the increase was by 25.7 % in the midland AEZ ($p<0.01$).

3.6Climate trend analysis nexus with farmers' perceptions

It is evident that farmers' perceptions of climate change in the last two decades' correlates with the meteorological data in the study area. Over 60 % of farmers have perceived increasing temperature and decreasing rainfall in all AEZs. Likewise, the trend analysis reveals that positive trends were observed in the ATmax, 0.02°C/year ($p<0.01$) in the lowland AEZ and 0.04°C/year ($p<0.01$) in the highland AEZ, respectively. The trend for ATmin was consistent in all AEZs and significant ($p<0.01$). Regarding rainfall trend, a non-significant decreasing trend was observed (1.80 mm/year) and (0.11 mm/year) in the lowland and highland AEZs, respectively. However, an increasing trend in the ATR (10 mm/year) ($p<0.05$) was experienced in the midland AEZ between 1983 and 2014. There are increasing temperature and decreasing rainfall trends both in the lowland and midland AEZs. Similarly, many studies in Ethiopia reported positive trends in the average ATmax (Degefu & Bewket, 2014; Eshetu *et al*., 2014; Gedefaw *et al*., 2018; Weldegerima *et al*., 2018; Worku *et al*., 2018) an increasing trend in the average ATmin (McSweeney *et al*., 2008; Keller, 2009; Eshetu *et al*., 2014; Mengistu *et al*., 2014). The total rainfall trend in two of the AEZs agrees with most of the empirical studies in Ethiopia (NMA, 2007; McSweeney *et al*., 2008; Gebremicael *et al*., 2013; Tekleab *et al*., 2013) that found neither decreasing nor increasing patterns in the total rainfall amounts. Nevertheless, the positive trend on the average total rainfall in the midland AEZ contradicts with household perceptions in the same AEZ over the study periods. The increasing trend in the ATR in the midland AEZ corroborates the results of Degefu and Bewket (2014) and Esayas *et al*. (2018b) that reported that the midland AEZ experienced an increasing trend in the average ATR.

Nonetheless, the discrepancy between farmers' perception of rainfall amount in the midland AEZ and the climate trend could be attributed to farmers' level of perception which are influenced by a number of factors including, agro-ecology, education, farm experience, resource endowments, access to climate information and early warning systems (Deressa *et al*., 2011; Tesso *et al*., 2012b; Habtemariam *et al*., 2016; Abrha & Simhadri, 2017; Asrat & Simane, 2018)while the trend is a cumulative result over three decades. Tadesse *et al*. (2017) observed similar discrepancies between the climate trend analysis and farmers' perception in the adjacent area of the study AEZs. Therefore, farmers' perception cannot merely depend on the actual climate conditions and a change in the climate parameters. Instead, it can be affected by a number of social, economic, demographic and institutional factors (Tesso *et al*., 2012b; Habtemariam *et al*., 2016; Asrat & Simane, 2018).

3.7Conclusion and recommendations

This study has analyzed trends of climate variability and farmers' perception in Southern Ethiopia using meteorological time-series data from 1983 to 2014. Understanding the temperature and rainfall variability trends and farmers' perception of changes in the climate among agro-ecological settings would offer valuable information for the planning and implementing local-level adaptations. The livelihood activities of most rain-fed farmers of the study area depend on the numerous climatic variables, mainly rainfall. The annual trend analysis of temperature and rainfall was carried out at agro-ecological *Zone* level. While the survey was conducted at households' level representing three different (highland, midland, and lowland) AEZs. The Mann–Kendall trend analysis confirms that there was a significant upward trend in the annual minimum temperature across AEZs while the annual maximum temperature has exhibited both upward and downward trends.

The Sen's slope confirms that the magnitude of change for the minimum temperature is faster than the maximum temperature both in time and space. The inter-annual variability of the annual maximum temperature suggests that AEZs have unveiled both warm and cool years during the 32 years, informing the recent years are warmer compared to the earlier years. The general warming trend observed in the study area agrees with empirical studies reported both at national and the local levels. The Mann–Kendall trend analysis reveals that there was an insignificant downward trend observed in the annual total rainfall both in the highland and lowland AEZs whereas a significant upward trend was detected in the midland AEZ, indicating mixed results. Standardized rainfall anomaly confirms that the study AEZs have experienced many drought years between 1983 and 2014 that also fits to the nation's worst drought years.

The study established that farm households are increasingly becoming aware of local climate change. Hence, farmers of Wolaita *Zone* have been facing the adverse impacts of climate variability and change as it impacted their lives and livelihoods over the last three decades. Results from the binary logit model inform that farmers' climate change perceptions are significantly influenced by their access to climate and market information, agro-ecology, education, agricultural input, and village market distance. The study concluded that farmers' perception of climate change reflects the meteorological analysis, although their perceptions were grounded on local climate factors. Based on these results, it is recommended to enhance farm households' capacity by providing timely weather and climate information along with institutional actions, including agricultural extension services, farm input suppliers, and viable livelihood diversification options. However, this study was limited in scope and sample size, it is suggested to undertake further studies at a larger scale to figure out the links between farmers' perceptions of climate change with meteorological data, in general, and explore socio-economic and contextual factors affecting climate change perceptions, in particular.

Chapter four

4 Farmers' livelihoods vulnerability to climate variability and change over Agro-ecological *Zone*s in Southern Ethiopia

Abstract

Climate variability and change is impacting climate-sensitive livelihoods in Ethiopia and the country is often labeled as highly vulnerable. The exposure, sensitivity, and adaptive capacity of agricultural livelihoods to such changes vary by agro-ecological settings and these remain a bottleneck to climate-resilient development strategy. The objective of this study is to assess agro-ecology specific livelihood vulnerability of farmers to climate variability and change over three agro-ecological *Zone*s in Wolaita, Southern Ethiopia. A total of 403 household heads were selected using a multistage sampling technique covering 11 villages (three highland, five midland and three lowland), respectively. In addition, 32 years of meteorological data, 11 focus group discussions, 15 key informant interviews, and personal observations were used to complement the survey data. We adapted the livelihood vulnerability index of the Intergovernmental Panel on Climate Change vulnerability framework to measure the livelihood vulnerability of farm households located in three agro-ecological *zone*s. The results showed that the livelihood vulnerability of farm households was considerably influenced by exposure, such as climate variability and change and natural disaster, sensitivity, such as agriculture and land use and sustainability, and adaptive capacity, including wealth, technology, infrastructure, knowledge or skills, livelihood strategy, socio-demography, and social networks. The results confirm that the lowland agro-ecology has relatively a higher exposure and sensitivity to climate shocks with a comparatively limited adaptive capacity. On the other hand, the midland agro-ecology shows the lowest vulnerability with a relatively lower perceived exposure and a higher adaptive capacity. Therefore, it is recommended that early warning systems be strengthened, and the practice of drought-tolerant varieties, weather-indexed insurance, and agroforestry designed to the specific agro-ecology should be encouraged to reduce further vulnerability to climate impacts and enhance their adaptive capacity.

Keywords: Exposure, sensitivity, adaptive capacity, livelihood vulnerability, agro-ecology.

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4.1 Introduction

The reality of climate change is increasingly gaining recognition in scientific and political arenas (Dube & Phiri, 2013). Sub-Saharan Africa has been recognized as one of the most vulnerable regions to climate change impacts since many places in this region inherently receive unpredictable rainfall (IPCC, 2014; Serdeczny *et al*., 2017). The recent IPCC report indicates that the scale and scope of adverse climate impacts will be higher on local people (IPCC, 2014). It is also argued that the vulnerability of livelihoods is mainly associated with a high exposure and low adaptive capacity (IPCC, 2014). Owing to this, the negative impacts of climate trends have been more common than the positive ones (IPCC, 2013).

The concept of vulnerability, coined from the Latin term *vulnerare*, expresses the potential to be maimed (Lei *et al*., 2014). In academia, vulnerability is currently conceptualized differently depending on the research discipline (Bergstrand, Mayer, Brumback, & Zhang, 2015; Wisner, 2016). In the context of climate change, vulnerability is often viewed as a function of exposure to a hazard, sensitivity to the hazard, and the ability to respond to the hazard (Adger, 2006; Parry *et al*., 2007). The IPCC has also defined vulnerability to climate change as "…*the degree to which systems are susceptible to and unable to cope with [the] adverse impacts of climate change, including climate variability and extremes*" (IPCC, 2007, p.883). Currently, climate change scholars accentuate on the predisposition to be adversely affected by disasters (IPCC, 2014).

Due to variations in the understanding of vulnerability, studies at different time and space have examined vulnerability from multiple perspectives, frequently from biophysical and social vulnerability angles (Limsakul *et al*., 2014). The biophysical vulnerability understands the adverse impacts of a hazard event due to the frequency and severity of a given type of hazard (Adger, Arnell, & Tompkins, 2005) whereas social vulnerability is considered as an inherent characteristic of a system that arises from a hazard event of a given nature and severity (Adger, Brooks, Bentham, Agnew, & Eriksen, 2004). Following the IPCC's understanding of vulnerability as a function of exposure, sensitivity and adaptive capacity (IPCC, 2012; IPCC, 2014), in this study, IPCC's vulnerability definition and the integrated vulnerability assessment framework was adapted. This is because the study centers on the IPCC's conceptual and analytical framework of vulnerability to assessing farmers' vulnerability to climate variability and change in three AEZs of the study area.

Climate variability and change is impacting climate-sensitive livelihoods in Ethiopia and the country is often labeled as highly vulnerable (Conway & Schipper, 2011). Empirical studies have reported Ethiopia's vulnerability to climate change impacts, which is highly associated with a high dependency on climate-sensitive sectors for livelihoods, pervasive environmental degradation and fragile ecosystems, and low adaptive capacity (Eshetu *et al*., 2014; Bewket *et al*., 2015; EPCC, 2015; Savage *et al*., 2015; Simane *et al*., 2016). A projection also indicates that Ethiopia will experience serious and negative influences linked to the changing climate patterns in the decades to come (Savage *et al*., 2015).

In Wolaita *Zone*, the study area, the adverse impacts of climate variability and change are high and put livelihoods at risk. These risks can be attributed to the impoverished livelihoods, unfavorable coping strategies, and poor resilience capacities. For example, empirical studies account that large proportion farming communities in Wolaita are in a precarious food security and their situation is aggravated by climate impacts (Gecho *et al*., 2014b; Abo & Kuma, 2015; Leza & Kuma, 2015; Tantu *et al*., 2017; Gazuma, 2018). Moreover, Wolaita is one of the most vulnerable and drought-prone areas in Ethiopia due to its high population density, critical shortage of farmland, pervasive environmental degradation, extreme poverty and chronic food insecurity, and limited livelihood options (Rhamato, 2007; Gecho, 2017; Bedeke *et al*., 2018; Esayas *et al*., 2018a; Gazuma, 2018). However, comprehensive evidence that documents the farming communities' exposure, sensitivity and adaptive capacities to deal with the adverse impacts of climate variability and change is lacking.

The literature review showsthat some empirical studies have been conducted focusing on the livelihood vulnerability to climate variability and change at household level in parts of Ethiopia. For example, Tesso *et al* (2012) analyzed the vulnerability and resilience levels of farm households in North Shewa. The study reported that farmers living in the highland areas were very much vulnerable to natural shocks compared to those living in the lowland area. On the other hand, few others, including Simane *et al*. (2016) have investigated agro-ecosystem specific climate vulnerability analysis in the tropical highland region. Dechassa *et al*. (2017) examined farmers' vulnerability to climate change in Didesa sub-basin of the Blue Nile basin. Amare and Simane (2017) estimated and compared the level of vulnerability of smallholder farmers to climate variability and change in the Muger River Sub-Basin of the Upper Blue Nile Basin. Asart and Simane (2017) assessed agro-ecology specific vulnerability of smallholder farmers to climate variability and change in the Dabus Watershed in North-West Ethiopia. Recently, Tessema and Simane (2019) studied agro-ecosystem specific vulnerability of smallholder farmers to climate variability and change in the Fincha sub-basin the Upper Blue Nile Basin.

The aforementioned empirical studies from agro-ecology and agro-ecosystem perspective reveal that smallholders' vulnerability to climate variability and change have significantly been influenced by their exposure and high level of sensitivity to climate shocks, and existing adaptive capacity. It was evident that across the studies, farmers of the lowland or dry land had higher exposure, sensitivity and limited adaptive capacities making them more vulnerable to climate stress. On contrary, the studies identified that the farmers of the midland or wetland areas were less sensitive with low exposure and higher adaptive capacity while the wetland and highland farmers were found to be moderately vulnerable to shocks.

Although these studies have contributed both conceptually and methodologically through agro-ecology and agro-ecosystem focused investigation of farming communities to climate variability and change in their study contexts, most of them are geographically confined to the Upper Blue Nile Basin, Central, and North-West Ethiopia. Therefore, none of their evidence can totally illuminate and capture the vulnerability conditions of smallholder or micro holder farmers in the context of our study area. In this connection, Simane *et al*. (2016) argue that results of vulnerability study at higher level cannot capture the complexity of vulnerability at the local level. Hence, owing to the social, economic and environmental contextual differences between the previous studies and the current one, it imperative to estimate and map out farm households' vulnerability situations to the changing climate at three agro-ecological settings of Wolaita, Southern Ethiopia. This will enable the planning and implementations of agro-ecology specific adaptation strategies and to design effective resilience-building interventions at this particular sub-regional state.

This paper measures the farmers' livelihood vulnerability to climate variability and change through empirical evidence from three AEZs in Wolaita *Zone*, Southern Ethiopia. The study aims to, a) measure and compare farmers' livelihood vulnerability to climate variability and change and b) examine the exposure, sensitivity and adaptive capacity components of farmers in the three AEZs. A customized and comprehensive livelihood vulnerability study results will contribute to the vulnerability literature by offering some empirical evidences of agro-ecology specific vulnerabilities of Southern Ethiopia.

4.2 Research design, sampling technique, and data analysis

The study used a quantitative-dominant convergent parallel mixed research design to assess farmers' livelihoods vulnerability to climate variability and change over three AEZs of Wolaita *Zone*, Southern Ethiopia. In doing so, both the quantitative data and qualitative information were collected concurrently. In selecting representative sample households, a three-stage sampling procedure was followed. In the first stage, three districts, including Damote Gale (highland AEZ), Sodo Zuria (midland AEZ), and Duguna Fango (lowland AEZ), were selected purposively (Figure 1.8). The criteria for selection include a district with dominant AEZ, vulnerability, demographic and livelihood conditions. In the second stage, following the characterization of the AEZs by Gecho*et al*. (2014a), list of all villages in the selected AEZs were used to further cluster them into the respective AEZs. Hence, a proportional three highland, five midland, and three lowland villages were selected randomly (Figure 1.8). Lastly, a probability proportional to size technique was applied to randomly select 403 farm household heads, after a representative size was determined using Kothari (2004).

Household survey was conducted from February to April 2017 through standard structured questionnaire administered by trained enumerators (i.e., eight members of the teaching staff at the Wolaita Sodo University) who speak the local language along with farm-level agricultural extension agent in each AEZ. The collected data were framed along 11 (eleven) major components of adapted for this study, including climate variability and change (CCV), natural disaster (ND), land use and sustainability (LUS), agriculture (A), wealth (W), technology (T), infrastructure (I), knowledge/skill (KS), livelihood strategy (LS), socio-demographic (SD), and social networks (SN) (Figure 4.1 and Annex 4.1). In addition, exposure data were obtained from the national meteorological agency (1983-2014) representing the three AEZs (Figure 1.8). To triangulate the quantitative data, the study employed 11 focus group discussions, 15 key informant interviews and field observation across the three AEZs. Based on these data, two types of analysis were undertaken: calculation of a balanced weighted average LVI and computation of LVI based on the IPCC framework for the respective AEZ (IPCC, 2007; IPCC, 2014). Quantitative data management and analysis was carried out in CS-pro ®6.3 and Stata®14. To statistically compare variables between and among livelihood vulnerability components, analysis of variance (ANOVA) was employed for interval variables. A thematic analysis, including description and classification of data, and seeing how concepts interconnect was employed for the qualitative information (Bazeley, 2009).

4.2.1 Approaches to measuring vulnerability

Different scholars used diverse approaches to measure and analyze vulnerability in different geographies of scales. However, vulnerability measurement has been dominated by three approaches-socio-economic, biophysical (impact assessment), and the integrated assessment in analyzing vulnerability to climate change (Deressa *et al*., 2008; Tesso *et al*., 2012a; Tessema & Simane, 2019). The socio-economic vulnerability assessment approach centers on the socioeconomic and political status of individuals or social groups and attempts to analyze their social vulnerability focusing on their economic and political conditions (Füssel, 2007; Deressa*et al*., 2008). Therefore, vulnerability, in this case, is viewed as a starting point that occurs within a system before it meets hazards (Birkmann, 2006; IPCC, 2014). This approach has been criticized for highly emphasizing variations within society and disregarding environmental factors in influencing vulnerability conditions (Deressa*et al*.,2008; Tesso *et al*., 2012a; Tessema & Simane, 2019).

The biophysical vulnerability method, on the other hand, measures the level of damage that a given environmental stress causes to both social and biological systems. Particularly, it focuses on the physical impact of climate change on different features, including income and yield (Füssel& Klein, 2006). It is widely used in vulnerability to natural hazards and climate change studies (Birkmann, 2006). It is criticized for its focus on bio-physical damages and sensitivity while ignoring the adaptive capacity of individuals or social groups (Deressa*et al*.,2008; Tesso *et al*., 2012a; Asrat & Simane, 2017; Tessema & Simane, 2019).

Cognizant of the shortcomings of these methods, the third approach combines both the socioeconomic and bio-physical approaches to determine vulnerability and is considered as an integrated assessment approach (Tesso *et al*., 2012a). In the context of climate change, vulnerability is taken an intertwined function of exposure, sensitivity and adaptive capacity (Adger, 2006; IPCC, 2014). In view of this, Füssel and Klein (2006) noted that the biophysical approach matches mostly to sensitivity in the IPCC framework. Füssel (2007) also suggests that adaptive capacity is generally consistent with the socio-economic approach. Hence, the integrated assessment approach addresses the limitations of the two approaches (Deressa *et al*., 2008; Simane *et al*., 2016; Asrat & Simane, 2017; Tessema & Simane, 2019). However, Deressa*et al*. (2008) observed that the integrated approach lacks a standard method for combining both the bio-physical and socio-economic indicators. In order to offset the shortcoming of using a single approach to measure vulnerability, this study employed the integrated approach to determine households' vulnerability conditions to climate variability and changeover three AEZs.

In terms of measurements, Deressa *et al*. (2009) recognized the two frequently used approaches (i.e., econometric and indicator-based) to measure vulnerability to climate variability and change. The econometric technique follows the use of econometric methods such as regression analysis. The problem with this technique is relates to testing various econometric assumptions (Etwire *et al*., 2013). The second approach is based on the indicator. It contains the selection of indicators that the researcher finds mainly account for the vulnerability (Deressa *et al*., 2009; Etwire *et al*., 2013; Tewari & Bhowmick, 2014; Tessema & Simane, 2019). In this approach, the subjectivity of the variable selection process is seen by many as a limitation (Etwire *et al*., 2013).

In spite of this limitation, recently different scholars applied the indicator-based approach to construct LVI in different contexts, including Ethiopia (Etwire *et al*., 2013; Tewari & Bhowmick, 2014; Simane *et al*., 2016; Asrat & Simane, 2017; Dechassa *et al*., 2017; Adu *et al*., 2018; Amuzu, *et al*., 2018; Tessema & Simane, 2019). Similarly, this study adapted the indicator-based approach to develop LVI of farm households to climate variability and change in the study AEZs.

4.2.2 Calculation of LVI and LVI-IPCC

The computation of LVI follows the sustainable livelihood approach (SLA) (Scoones, 2009) and the LVI-IPCC approach used in the aforementioned studies. In doing so, it applies a balanced weighted average approach (Sullivan, Meigh, & Fediw, 2002) wherein each sub-component contributes equally to the overall index even if each major component comprises of a different number of sub-components. Since each major component is composed of different number of indicators measured on different scales such as percentage, ratio, and indices, the data transformation was done by taking the functional association between indicators and livelihood vulnerability (UNDP, 2007; UNDP, 2014; Adu *et al.*, 2018) using equations 4.1 and 4.2. Equation (4.1) was applied where a sub-component had a positive relationship with vulnerability and equation (4.2) was used for a sub-component and vulnerability to have a negative relationship.

$$I_a = \frac{Sr - S_{\min}}{S_{\max} - S_{\min}} \quad (4.1)$$

$$I_a = \frac{S_{\max} - S_r}{S_{\max} - S_{\min}} \quad (4.2)$$

Where I_a is the standardized value of the indicator a, S_r is the observed (mean) value of the indicator for AEZ r, $S_{\min}$ and $S_{\max}$ are minimum and maximum values of the indicator across all the AEZs, respectively. After each indicator was normalized, the mean value of each major component was calculated using equation 4.3:

$$M_r = \frac{\sum_{a=1}^{n} I_{a_i}}{n} \quad (4.3)$$

Where M_r is one of the 11 major components tailored to the study AEZs: Climate variability and change (CCV), Natural Disaster (ND), Land Use and Sustainability (LUS), Agriculture (A), Wealth (W), Technology (T), Infrastructure(I), Knowledge/Skill (KS), Livelihood Strategy (LS), Socio-Demographic (SD), and Social Networks (SN) (Figure 4.1 and Annex 4.1) for AEZ r, I_{a_i} is the indicator indexed value by i , which forms each major component and n is the number indicator of each major component. Once values for each of the 11 major components for each AEZ were computed, the LVI was obtained from the weighted average of all the major components applying equation 4.4:

$$LVI_r = \frac{\sum_{p=1}^{11} W_{m_i} M_{r_i}}{\sum_{p=1}^{11} W_{m_i}} \quad (4.4)$$

This can be further stated as equation 4.5:

$$LVI_r = \frac{WCCV^{CCV_r} + WND^{ND_r} + WLUS^{LUS_r} + \cdots\cdots + WSN^{SN_r}}{WCCV + WND + \ldots\ldots + WSN} \quad (4.5)$$

Where LVI_r is the livelihood vulnerability index for AEZ r, W_{mi} is the weight of major component i, and M_{r_i} the number of indicators of the major component (Figure 4.1 and Annex 4.1). In this study, LVI value ranges between 0 and 1 where 0 denotes the least vulnerable and 1 indicates the most vulnerable (Etwire *et al*., 2013; Tewari & Bhowmick, 2014; Simane*et al*., 2016). Based on equations (1) to (3), Hahn, Riederer, and Foster (2009) computed the major components of LVI based on the LVI-IPCC vulnerability classification into Exposure (E), Sensitivity (S), and Adaptive Capacity (AC) as expressed in equation 4.6:

$$CF_r = \frac{\sum_{i=1}^{f} W_{m_i} M_{r_i}}{\sum_{i=1}^{f} W_{m_i}} \quad (4.6)$$

Where, CF_r is the LVI-IPCC defined contributing factors (E, S, AC) for AEZ r, W_{mi} is the weight of major component and M_{r_i} are the major components for AEZ r indexed by i, f is the number of profiles associated with the contributing factor, and p is indexed to the profiles or components associated with the CF. Following Hahn *et al*. (2009), each of the computed and three major contributing factors were combined using equation 4.7:

$$LVI - IPCC_r = (e_r - a_r) * s_r \quad (4.7)$$

Where $LVI - IPCC_r$ is the LVI for AEZ r stated in the IPCC vulnerability framework, e_r is the computed exposure score for AEZ r, a_r the computed adaptive capacity score for AEZ r, and

s_r is the calculated sensitivity score for AEZ r. The LVI-IPCC index is scaled from -1 (least vulnerable) to 1 (most vulnerable). It is mostly used as an estimate to the relative vulnerability compared to the populations in the agro-ecology (Etwire *et al*., 2013; Tewari & Bhowmick, 2014; Simane *et al*., 2016; Adu *et al*. 2018; Tessema & Simane, 2019).

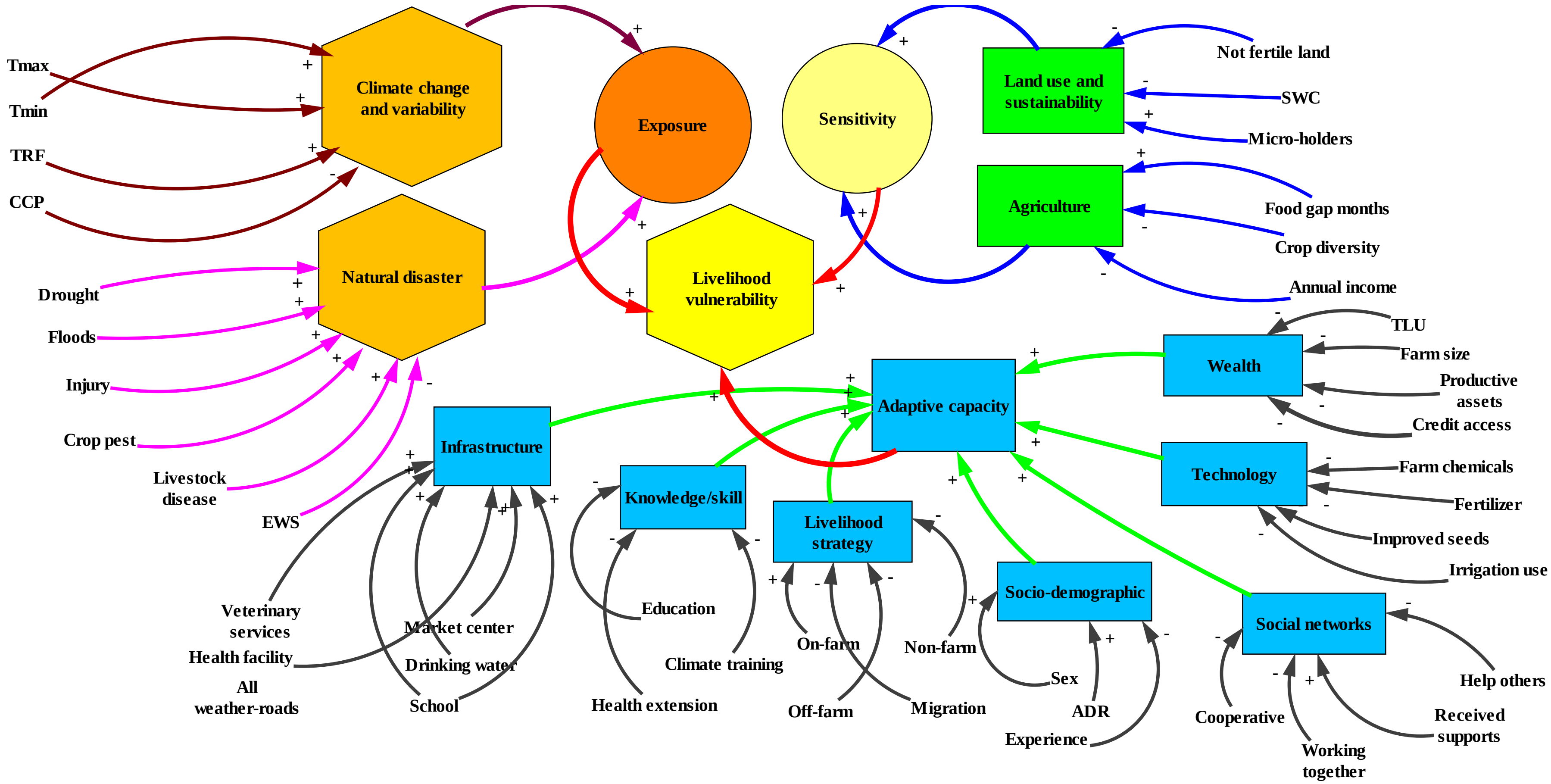

Figure 4.1 Livelihood vulnerability analytical framework

4.3 Results and discussions

4.3.1 Exposure profile: climate variability and change, and natural disaster

Exposure refers to the nature and degree of a system's exposure to significant climate variations/natural hazards (IPCC, 2007; Hahn *et al*., 2009). In this study, the exposure profile entails two major components that fall in the natural capital group. These major components are climate variability and change, and natural disaster, which in turn include 11 sub-components or indicators (Figure 4.1 and Annex 4.1). Over 60 % of farmers perceived increasing temperature and decreasing rainfall during the last two decades across AEZs. The qualitative information complements this reality. The following extract from a focus group discussion summarizes farmers' perception about temperature and rainfall in the last two decades:"*In 1999 E.C, the area was very green and we had adequate pasture for the cattle. Today, there is no grass for grazing and there is a movement in search of grass. Since 1999 E.C, we have witnessed a decrease in rainfall and an increase in temperature warming. The springs have been dried and the vegetation cover has been declining. Where there is irrigation, production of crops is good, which is also decreasing rapidly.*"

This also agrees with empirical studies reported in other parts of Ethiopia (Simane *et al*., 2016; Amare & Simane, 2017; Asrat & Simane, 2017; Dechassa *et al*., 2017; Tessema & Simane, 2019). Similarly, the trend analysis reveals that positive trends were observed in the maximum temperature, 0.02°C/year ($p<0.01$) in the lowland and 0.04°C/year ($p<0.01$) in the highland AEZ, respectively. The trend for the minimum temperature was consistent in all AEZs and significant ($p<0.01$). Regarding rainfall trends, a non-significant decreasing trend was detected (1.80 mm/year) and (0.11 mm/year) in the lowland and highland AEZs, respectively. Nevertheless, an increasing trend was recorded (10 mm/year) ($p<0.05$) in the midland AEZ between 1983 and 2014 (Table 4.1). On this account, the exposure analysis suggests that a high score of climate variability and change component in the lowland with 0.448, followed by 0.427 and 0.388 in the highland and in the midland, respectively.

Table 4.1 Average precipitation and temperature

Agro-ecology	Altitude (masl)	Area (ha)	Min (ºC)	Sen's Slope (ºC/year)	Max (ºC)	Sen's Slope (ºC/year)	Ave. annual rainfall (mm)	Sen's Slope (mm/year)
Highland	1501-2958	235.5	13.64	0.05***	25.50	0.02***	881.13	-1.80
Midland	1501-2958	347.8	14.86	0.05***	26.59	-0.01	1180.91	10*
Lowland	1000-2500	401.5	14.80	0.07***	27.87	0.04 ***	696.66	-0.11

*** Significant at p<0.01; ** Significant at p<0.05; * Significant at p<0.1 level

With regard to the natural disaster contributing factors, 73.45 %, 71.71 %, .55.08 %, and 44.66 % of farmers reported facing drought, crop failure, floods, and livestock disease, respectively over the last two decades (Table 4.4). Due to these factors, the natural disaster score indicates that both the lowland (0.571) and highland (0.58) AEZs have high scores and the midland has the lowest score (0.49), suggesting highland and lowland areas are more prone to natural disaster compared to the midland. Esayas *et al*. (2018b) reported that both the lowland and highland AEZs have experienced a rapid rate of changes in extreme climate events, which heighten the vulnerability of poor farmers in the same AEZs. Most farmers also reported experiencing frequent droughts, floods, livestock diseases and crop failures over the last two decades (Table 4.2). For instance, in 2016/2017 alone, a total of 3026 hectares of land was affected by flooding near the Bilate river which resulted in the death of 981 livestock population, and 12,126 households remain victims (WZFED, 2017). Moreover, the standardized rainfall anomaly (SRA) result established that 50 % of all AEZs had faced drought years between 1983 and 2014, which corresponds with the nation's worst drought years (McSweeney *et al*., 2008).

In support of this, evidence from the qualitative information vividly noted that "*drought occurrence continuously increased from time to time and begun to happen on a yearly basis. For example, due to El Niño, we faced a drought last year (2016), which affected animals and caused even complete crop failure. There was also the outbreak of pest (virus) that damaged maize. This was a strange phenomenon.*" This might be also attributed to lack of early warning system (EWS) services in the area. For example, over 65 % of farmers did not have access to EWS in all AEZs while it was about 62 % for the highland and 60 % for lowland AEZs. By the same token, one of the key informants from the lowland AEZ noted the lack of EWS as follows: "*There are no proactive measures to undertook before the shock happens. We always react after the shock. Every year, a study is conducted on the level and* *magnitude of vulnerability to shocks, which is jointly done by a multi-agency team drawn from federal, regional and zonal institutions. Nonetheless, the proactive measures are poor*." The finding agrees with the results of the study by Amare and Simane (2017) in Muger sub-basins where they reported large proportion of farmers who did not have access to EWS were exposed to natural disasters such as drought and floods.

On the basis of the two major components and the corresponding indicators, the lowland AEZ is more vulnerable by exposure vulnerability factor (EVF) (0.522) while the midland AEZ was the least vulnerable by EVF (0.449), which also increases their level of vulnerability in the face of climate variability and change (Figure 4.2). Empirical studies in different contexts reported a differentiated exposure level of farmers residing in different agro-ecological settings (Simane *et al*., 2016; Amare & Simane, 2017; Asrat & Simane, 2017; Dechassa *et al*., 2017; Tessema & Simane, 2019).

Table 4.2 Exposure LVI along with indexed major and sub-components

Sub-component (indicators)	HL	ML	LL	Component	HL	ML	LL
Mean SD of Ave. monthly maximum temperature (ºC) (1983-2014)	0.479	0.434	0.51	Climate variability and change	0.427	0.388	0.448
Mean SD of Ave. monthly minimum temperature (ºC) (1983-2014)	0.404	0.413	0.5				
Mean SD of Ave. monthly precipitation (mm) (1983-2014)	0.503	0.314	0.358				
% of HHs that did not perceive climate change over 20 years	0.322	0.389	0.426				
% of HHs reporting drought occurrences over 20 years	0.789	0.707	0.739	Natural disaster	0.58	0.49	0.571
% of HHs reporting floods occurrences over 20 years	0.644	0.444	0.661				
% of HHs reporting injury of a family member due to climate	0.133	0.056	0.122				
% of HHs reporting crop disease/pest outbreak over 20 years	0.778	0.667	0.757				
% of HHs reporting livestock disease outbreak over 20 years	0.511	0.364	0.539				
% of HHs who did not receive a warning about natural disaster	0.622	0.702	0.609				
Exposure LVI					**0.519**	**0.449**	**0.522**

4.3.2 Sensitivity profile: Land use and sustainability, and agriculture

Sensitivity denotes the degree to which a system is affected, either adversely or beneficially, by climate/natural hazard-related stimuli (IPCC, 2007). The sensitivity profile involves two major components that fall in the natural capital category (Figure 4.1). The contributing factors include land use and sustainability and agriculture, which again comprises of 6 sub-components (Figure 4.1 and Table 4.3). It is evident that Wolaita *Zone* is one of the most degraded and fragmented areas in Ethiopia and the region (Rhamato, 2007; Cochrane, 2017). About two-thirds of the farmers reported that the land is not fertile in all AEZs, which is one of the main factors negatively affecting agricultural production. In terms of AEZs, most of the infertile land (75.7%) was reported by farmers in the lowland areas while relatively fertile land belongs to those in the highland AEZ (43.33%). It is clear that the expansive farming towards sloppy lands, loss of topsoil and declining forest coverage are some of the contributing factors of land infertility. The qualitative information supports the declining land fertility as "*The land fertility has decreased and it is not providing yield without fertilizers. The farmlands are frequently plowed and its fertility is declining. There is no gap in farming in our locality*". In response to this, the use of soil and water conservation (SWC) has been taken as one of the mechanisms to improve soil fertility and enhance agricultural production. However, 50 % of the farmers in the midland AEZ did not use SWC to address the soil infertility challenges while those in the lowland and highland AEZs have practiced SWC.

As Rhamato (2007) calls most farmers in Wolaita as "micro-holders" (0.1 to 0.5ha), the field data also shows that 63.5 %, 56.6 %, and 54.4 % are "micro holders" in the lowland, midland and highland AEZs, respectively (Table 4.3). In addition, population pressure, a common problem across all three AEZs, results in a declining farm size per household and limits the application of SWC further aggravating vulnerability of micro-holders' to climate-induced shocks. The land use and sustainability score informs that the midland has the highest score of 0.59, followed by the lowland (0.559) and the smallest score was for those in the highland AEZ (0.433) (Table 4.3), suggesting that farmers in the midland AEZ are more sensitive compared to the highland AEZ. This result is in agreement with a recent study by Amare and Simane (2017), which reported that the midland AEZ of Muger sub-basin is more sensitive while the highland is the least sensitive to climate shocks.

In terms of livelihood activities, farm households in all AEZs practice mixed farming involving the production of cereals, root crops, *Enset*, and coffee. In addition, Wolaita *Zone* is primarily subdivided into two livelihood *Zone*s, namely, ginger and coffee, on one hand, and maize and root crops, on the other (Eneyew & Bekele, 2013). Due to these limited livelihood options, the average food gap months' ranges from 5.81 in the lowland to 4.2 months in the midland (Table 4.3). The figures suggest that households in the lowland AEZ experienced most food shortage months which again demonstrates the relative advantage of location in influencing farm household vulnerability to shocks. The food shortage month's figure is comparable among few empirical studies in the study area (Abo & Kuma, 2015; Leza & Kuma, 2015; Tantu *et al*., 2017; Gazuma, 2018). This partly contributes to a high sensitivity in relation to agriculture to climate shocks in the lowland (0.717) while midland (0.611) was relatively the smallest sensitive AEZ (Table 4.3).

Based on the overall computed indices for the sensitivity component, the lowland, midland, highland AEZs scored 0.638, 0.601, 0.547, respectively (Figure 4.2). Hence, given the two major components and the corresponding six sub-components, the sensitivity analysis states a high score for the lowland AEZ compared to the highland AEZ. This result explains the high sensitivity of the lowland to climate variability and change-induced shock. Similar observations were made by (Asrat & Simane, 2017; Tessema & Simane, 2019).

Table 4.3 Sensitivity LVI and corresponding major and sub-components

Sub-component (indicators)	HL	ML	LL	Component	HL	ML	LL
% of HHs with non-suitable cultivated land (not fertile land)	0.433	0.707	0.757	Land use and sustainability	0.433	0.591	0.559
% of HHs not practicing soil and water conservation	0.322	0.5	0.287				
% of HHs with micro-holders (0.1-0.5 ha)	0.544	0.566	0.635				
Ave. no. of food gap months from own production	0.44	0.35	0.485	Agriculture	0.661	0.611	0.717
Crop diversity score	0.647	0.567	0.734				
Annual income (sales of crop, livestock, non-farm, and off-farm) (Birr)	0.896	0.915	0.932				
Sensitivity LVI					**0.547**	**0.601**	**0.638**

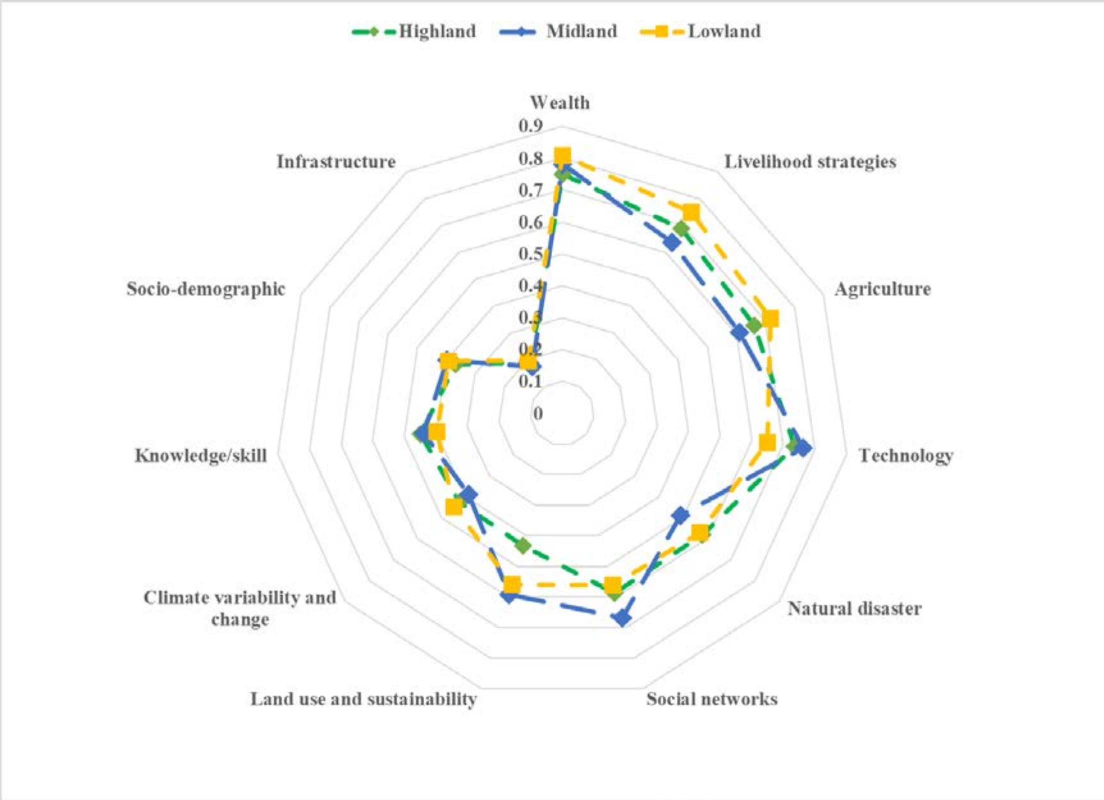

Figure 4.2 LVI major components by agro-ecological *Zone*s

4.3.3 Adaptive capacity profile: wealth, technology, infrastructure, knowledge, livelihood, socio-demographic and social networks

Adaptive capacity indicates a system's ability to adjust to climate change/natural hazards and moderate potential damages, take advantage of opportunities, or cope with the consequences (IPCC, 2007). In this study, the adaptive capacity profile encompasses seven major components classified under different livelihood capitals (financial, physical, human and social) (Hahn *et al*., 2009). The major components include wealth, technology, infrastructure, knowledge or skills, livelihood strategy, socio-demographic, and social networks, which in turn consists of 28 sub-components or indicators (Figure 4.1 and Table 4.4).

The wealth profile of the adaptive capacity is composed of four indicators: total livestock in TLU (inverse), cultivated farm size in hectares (inverse), estimated value of productive asset (inverse), and households' access to credit. Wealth variables, with an average index value of 0.751 in the highland AEZ, are the high influencing components on a vulnerability of highlanders than farmers in the other two agro-ecologies (Table 4.4).

In terms of total livestock holding (TLU), farmland ownership (hectare) and possession of productive asset (*Birr*), highlanders were found to be more vulnerable (less ability to adapt) compared to the other AEZs. Moreover, in terms of credit access, vulnerability of farmers of the highland was aggravated compared to other AEZs due to their comparatively limited access to credit (of whom only 21.1% had access to credit) (Table 4.4). The higher vulnerability of the highlanders may presumably be accounted for by low livestock ownership- the lowest among the three AEZs (3.076 in TLU) and low productive assets ownership (488.4 *Birr*) compared to farmers of the midland AEZ who had the largest TLU (3.969) and productive assets (1034.51 *Birr*). The mean difference is statistically significant across AEZs ($p<0.01$), suggesting the worst position of the highland farmers and their relative inability to withstand climate shocks (Table 4.5).

The qualitative information from the households' vulnerability mapping puts farmers of the highland AEZ as less positioned in relation to farmers of other AEZs. Previous studies also reported that farmers of the midland AEZs in the Upper Nile basin had higher adaptive capacity to offset climate variability and change shocks in relation to the dry land or lowland AEZ (Amare & Simane, 2017; Asrat & Simane, 2017; Tessema & Simane, 2019).

In term of technology, farmers' adaptive capacity was assessed through the use of agricultural chemical, fertilizers, improved seed, and irrigation practices. Accordingly, farmers of the lowland AEZ showed lesser vulnerability on the technology profile index than farmers in the rest AEZs. The difference in the technology score could be primarily attributed to the relatively high rate of fertilizer and improved seed applications in the lowland AEZ (73 and 58.3%, respectively) (Table 4.4). Moreover, although the farmers believe in the value of fertilizers and improved seeds in enhancing agricultural production, most farmers are not in a position to afford the input costs. In their view *"Fertilizer is a necessity for the land to grow, yet the price is beyond our capacity. This is one of the reasons for us to be impoverished."* As far as reducing farmers' vulnerability to shock is concerned, this could be one of the gaps that need to be addressed by the concerned bodies in all AEZs.

Table 4.4 Adaptive capacity LVI and corresponding major and sub-components

Sub-component (indicators)	HL	ML	LL	Component	HL	ML	LL
Livestock in total livestock unit (TLU)	0.65	0.707	0.76	Wealth	0.751	0.782	0.807
Cultivated farm size (ha)	0.779	0.799	0.907				
Estimated value of HH productive assets in (*Birr*)	0.785	0.919	0.925				
% of HHs who do not have access to credit	0.789	0.702	0.635				
% of HHs not using farm chemical	0.989	1.00	0.974	Technology	0.736	0.764	0.650
% of HHs not using farm chemical fertilizer	0.367	0.369	0.27				
% of HHs not using improved seed	0.622	0.732	0.417				
% of HHs not practicing irrigation	0.967	0.955	0.939				
Ave. time to reach human health facility (walking hours)	0.08	0.048	0.119	Infrastructure	0.188	0.173	0.194
Ave. time to reach into all weather-roads (walking hours)	0.193	0.053	0.085				
Ave. time to reach to school (walking hours)	0.221	0.371	0.194				
Ave. time to reach to veterinary services (walking hours)	0.132	0.093	0.228				
Ave. time to reach to drinking water (walking hours)	0.127	0.124	0.323				
Ave. time to reach market (walking hours)	0.373	0.351	0.214				
% of HH heads with no formal education	0.533	0.455	0.357	Knowledge/skills	0.448	0.438	0.397
% of HH heads not received climate-specific training	0.756	0.828	0.791				
% of HH heads not received health extension service	0.056	0.03	0.043				
% of households did not work in non-farm income	0.700	0.687	0.826	Livelihood strategy	0.689	0.636	0.750
% of HH did not work in off-farm income activity	0.511	0.359	0.600				
% of HHs that majorly depend on agriculture as source of income	0.956	0.955	0.948				
% of HHs that did not migrate outside the community	0.589	0.545	0.626				
% of female head households	0.344	0.369	0.304	Socio-demographic	0.368	0.398	0.392
Dependency ratio	0.227	0.196	0.331				
Farm experience	0.533	0.628	0.540				
% of households do not help others	0.389	0.359	0.313	Social networks	0.586	0.669	0.563
% of households who received help from others	0.622	0.697	0.722				
% of HHs not part of the *debo*-working together	0.478	0.742	0.400				
% of HHs not involve in cooperative membership	0.856	0.879	0.817				
Adaptive capacity LVI					0.522	0.534	0.522

In this study, access to infrastructure as one of the components of adaptive capacity was examined using average traveling distance to the human health facility, all weather-roads, school, veterinary services, drinking water, and market center. Accordingly, midland farmers were found to have a lesser infrastructure inaccessibility vulnerability (with an averaged index value of 0.173) compared to the farmers in the rest of the AEZs. Specifically, midland farmers were identified as less vulnerable in terms better access to human health facility, all weather-roads, veterinary services and drinking water (Table 4.4). This may be due to the fact that farmers in the midlands travel a shorter distance to reach drinking water and veterinary services (about 30 and 21.27 minutes, respectively) compared to the longest distance traveled by lowlanders (about 60 and 29.68 minutes, respectively). Moreover, midland farmers accessed human health facility and all-weather roads easily (14.41 and 9.87 minutes, respectively) compared to the highlanders (20.63 and 30.56 minutes, respectively). Such mean differences were verified to be statistically significant across all the AEZs ($p<0.01$) (Table 4.5). The possible justifications could be the rugged nature of the topography in most parts of the highland AEZ which takes longer walking distance compared to other AEZs. These reduce farmers' adaptive capacity in the face of climate variability and change shocks. These results are in agreements with the previous studies in different parts of Ethiopia (Simane *et al*., 2016; Amare & Simane, 2017; Asrat & Simane, 2017; Tessema & Simane, 2019).

Table 4.5 LVI components used in the ANOVA analysis for the three agro-ecological *zone*s

Variables	F-test
Food gap months	13.14***
Crop diversity score	47.82***
Aggregate income	4.45**
Tropic livestock unit	6.44***
Total land size	1.74
Productive asset	4.70***
Ave. time to reach human health facility	2.47*
Ave. time to reach to all weather-roads	25.97***
Ave. time to reach to school	11.53***
Ave. time to reach to veterinary services	3.09**
Ave. time to reach to drinking water	45.25***
Ave. time to reach market	20.50***
Dependency ratio	3.19**
Farm experience	10.58***

*** p<0.01; ** p<0.05; * p<0.10.

Both education and capacity building trainings have the potential to impact farmers' decision and positively contribute to local level climate change adaptation strategies. Relating the knowledge and skills of farmers, 53.33 % of farmers in the highland AEZ did not have formal education while only 35.65 % of farmers in the lowland AEZ had no formal education. Even though most farmers across AEZs did not have adequate climate-specific training, those in the highland AEZ had relatively better access (24.44 %) compared to those in the midland AEZ (17 %). With farmers' access to the health extension service, the midland AEZ had better access as it reached to 96.97 % of the households. Overall, farmers in the highland AEZ were found to be more vulnerable in terms of knowledge/skill profile (with an average index value of 0.448) compared to the farmers in the midland (0.438) and lowland (0.397) AEZs (Figure 4.2). The relatively better adaptive capacity of lowland farmers could be due to their better attainment of formal education (Table 4.4).

Livelihood strategies, assuming positive contribution of livelihood diversification to adaptive capacity, were examined using profiles, including participation in non-farm and off-farm income, level of dependency on agriculture as a source of income and migration (Figure 4.1). When all profiles were aggregated, midland farmers were found to be less vulnerable in terms of livelihood strategy (with an average indexed value of 0.636) compared to farmers in the rest of the AEZs. This value might be the result of relatively higher participation in non-farm (31.3%) and off-farm income (64.1%) and reliance on migration as a livelihood strategy (45.5%) among midland farmers compared to those in the lowland and highland AEZs. Other vulnerability studies in Ethiopia (Amare & Simane, 2017; Dechassa *et al.*, 2017) similarly show that midland AEZs perform better in terms of livelihood strategy vulnerability compared to lowland AEZ.

Socio-demographics had a higher vulnerability effect in the midland AEZ (with an average indexed value of 0.398) compared to the rest. This is contrary to the results reported by Amare and Simane (2017) where the vulnerability contribution of socio-demographics was founded to be higher in the lowland AEZ. This might be due to the relatively higher households headed by female heads (36.9%) and a higher dependency ratio (0.784) of farmers in the midland AEZ compared to female-headed farmers in the lowlands (30.43 %) and highlands (34.44 %). Differences in dependency ration and the farm experience among the AEZs were statistically significant ($p<0.05$) (Table 4.5).

The social network is another important profile taken into account to determine vulnerability of communities in the different AEZs. Overall, farmers in midland AEZ (with an average indexed value of 0.669) were more vulnerable in terms of social networks profile score than the highlanders and lowlanders, again contrary to the findings of Amare and Simane (2017), Dechassa *et al*. (2017) and Tessema and Simane (2019) where lowland AEZ were found to be more vulnerable in terms of social networks profile score. This is possibly because of higher proportion of households did not participate in *debo* (farmers working together) and were not members of farmer cooperatives (74.2 and 87.9%, respectively) in the midland AEZ in this study area.

4.4 LVI-IPCC contributing factors

In line with the LVI-IPCC methodology, the three contributing factors to climate change vulnerability-exposure, sensitivity, and adaptive capacity-were considered. Following this method, high values of exposure relative to adaptive capacity yield positive vulnerability scores while low values of exposure relative to adaptive capacity offer negative vulnerability scores. With its multiplier effect, high sensitivity in situations where exposure exceeds adaptive capacity results in high vulnerability (large positive score) whereas high sensitivity in situations where adaptive capacity exceeds exposure results in lower vulnerability (large negative score).

With this logic, the relative exposure was found to be a bit higher (0.519) while adaptive capacity is slightly lower (0.517) in lowland AEZ (Figure 4.3). Coupled with the relatively higher sensitivity (0.638) in lowland AEZ (compared to the rest of the AEZs), this resulted in a positive vulnerability score (0.00013) implying relatively higher livelihood vulnerability of lowlanders compared to farmers in the highland (-0.00197) and in the midland (-0.05099) (Table 4.6). On the other hand, the lower exposure (0.4490) and higher adaptive capacity (0.5339) of the midland AEZ compared to the rest (Figure 4.3), resulted in a relatively large negative vulnerability score (-0.05099) in the midland AEZ, showing that the overall vulnerability is estimated to be low in the midland AEZ compared to the lowland and highland AEZs. The highland AEZs exhibits intermediate vulnerability value. In general, although the midland AEZ has high sensitivity to shock compared to the highland AEZ, due to its limited exposure and better adaptive capacity, it was found to be less vulnerable to climate variability and change compared to the other AEZs. This result was in line with findings of Dechassa *et al*. (2017) and Tessema and Simane (2019) whereas Amare &

Simane (2017) found highlanders were less vulnerable compared to the lowlanders and midland farmers. However, all related studies in Ethiopia agree that the lowland AZE is more vulnerable compared to the other AEZs (Amare & Simane, 2017; Dechassa *et al*., 2017; Tessema & Simane, 2019).

In short, in terms of exposure, the lowland (0.522), highland (0.519), and midland (0.44) AEZs had the indexed values, respectively. The lowland AEZ had a high sensitivity (0.638), followed by the midland AEZ (0.601), and the least being the highland AEZ (0.547). On the adaptive capacity, the midland AEZ had relatively a higher adaptive capacity (0.534) whereas both the lowland and highland AEZs owned the same adaptive capacity (0.522) to climate shocks. Overall, the lowland remains a highly vulnerable AEZ, followed by a moderately vulnerable highland AEZ, and the midland AEZ stands as a less vulnerable AEZ to climate shocks.

Table 4.6 Indexed major component, LVI-IPCC contributing factors and the overall LVI

Sub-component (indicators)	HL	ML	LL	Component	HL	ML	LL
Climate variability and change	0.427	0.388	0.448	Exposure	0.5186	0.4490	0.5219
Natural disaster	0.580	0.490	0.571				
Land use and sustainability	0.433	0.591	0.559	Sensitivity	0.5472	0.6007	0.6382
Agriculture	0.661	0.611	0.717				
Wealth	0.751	0.782	0.807	Adaptive capacity	0.5222	0.5339	0.5217
Technology	0.736	0.736	0.736				
Infrastructure	0.188	0.173	0.194				
Knowledge/skills	0.448	0.438	0.397				
Livelihood strategy	0.689	0.636	0.750				
Socio-demographic	0.368	0.398	0.392				
Social networks	0.586	0.669	0.563				
Overall LVI					**0.525**	**0.524**	**0.538**
LVI-IPCC =[Exposure-Adaptive capacity] × Sensitivity					**-0.00197**	**-0.05099**	**0.00013**

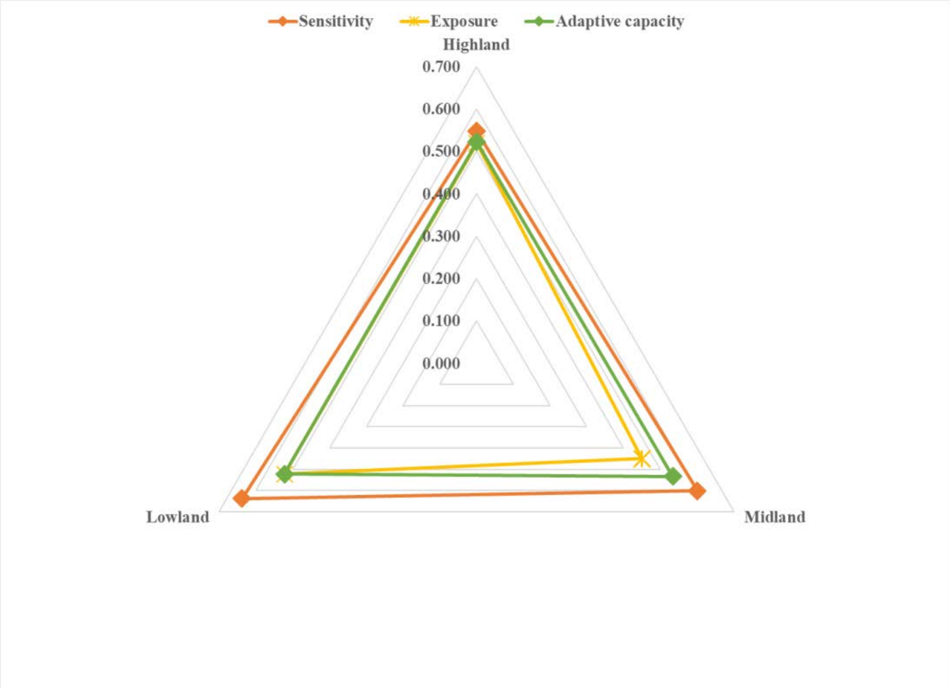

Figure 4.3 LVI-IPCC contributing factors by agro-ecological *Zone*s

4.5 Conclusion and recommendations

Climate variability and change is impacting climate-sensitive livelihoods in Ethiopia and the country is often labeled as highly vulnerable. The objective of the study was to assess agro-ecology specific livelihood vulnerability of farmers to climate variability and change over three agro-ecological *zone*s (AEZs) in Wolaita, Southern Ethiopia. The livelihood vulnerability index (LVI) and LVI-IPCC were computed based on the IPCC vulnerability framework consisting of exposure, sensitivity and adaptive capacity, which were customized to the local contexts. The study employed both primary and secondary data. The primary data was based on a survey of 403 farming households complemented by secondary data on rainfall and temperature over the period between 1983 and 2014. A comparative analysis was conducted for highland, midland, and lowland AEZs. The empirical results revealed that farming households' livelihood vulnerability to climate variability and change were considerably influenced by exposure such as climate variability and change, and natural disaster, sensitivity such as agriculture and land use and sustainability, and adaptive capacity including wealth, technology, infrastructure, knowledge or skills, livelihood strategy, socio-demography, and social networks. The trend in the exposure component not only mirrors the spatial pattern of vulnerability across AEZs but also pinpoints certain factors that play a leading role in determining the vulnerability of farming communities.

The study results suggested that the lowland agro-ecology has a relatively higher exposure and sensitivity to climate shocks and a comparatively limited adaptive capacity. On the contrary, the midland agro-ecology has a lowest vulnerability with a relatively lower perceived exposure and higher adaptive capacity. Moreover, the overall computed livelihood vulnerability index confirms that the lowland agro-ecology is relatively more vulnerable, followed by the highland and the midland, which is the least vulnerable to climate shocks. In short, the results can be one of the indications of farming households' high vulnerability to climate variability and change-induced shock, which adversely affected and put livelihoods at risk. On this account, the use of customized, comprehensive livelihood vulnerability indicators confirms the soundness of the IPCC vulnerability framework in explaining the local level vulnerability conditions to climate variability and change, which can be further replicated in similar contexts.

The results of this study have implications for the initiation and implementation of agro-ecology specific climate change adaptation strategies, and household resilience capacity-building projects by the government, donor agencies, and other related organizations in the study area. Therefore, the study recommends that existing early warning systems should be strengthen to enhance the provision of timely climate information and the practice drought-tolerant varieties, weather-indexed insurance, integrated natural resource management and improved breeds along with pasture management fitting the specific agro-ecology context to reduce further vulnerability to climate impacts and increase their adaptive capacity, should be encouraged.

This study contributes to the livelihood vulnerability discussion by highlighting the vulnerability of farming households located in the three AEZs to climate variability and change through the lens of the LVI-IPCC livelihood vulnerability frameworks using household-level data. Nevertheless, since this study focuses only on some selected districts of the study, to make informed policy decisions,it is imperative to undertake further study on mapping the livelihood vulnerability of smallholder farmers and the constraints of adaptation strategies in the face of changing climate on a wider geographic scale.

Chapter five

5 Livelihood resilience capacities and its determinants: evidence from three agro-ecological *Zone*s of Southern Ethiopia

Abstract

Building livelihood resilience requires reducing exposure and sensitivity to shock while increasing adaptive capacity. The study aims to measure farm household livelihood resilience capacities to climate-induced shocks and explore factors affecting their level of resilience in Wolaita *Zone*, Southern Ethiopia. A total of 403 household heads was selected using a multistage sampling technique covering 11 villages (three highland, five midland and three lowland). In addition, 11 focus group discussions, 15 key informant interviews, and personal observations were used to supplement the survey data. Then, livelihood resilience index of households was developed with a suite of livelihood capacity indicators. The results revealed that livelihood resilience capacities of farm households were substantially influenced by absorptive capacity such as support given to others, support received and membership in the charity group, adaptive capacity such as social capital-*iddir/equib*, credit access, working together-*debo*, crop diversity, and transformative capacity including access to health posts, all-weather roads, veterinary services, safe water, agricultural extension, and input use. Moreover, the mapped resilient quadrant locates 148 (36.72 %) of the households in Quadrant-III (highly vulnerable) and 139 (34.49%) households in Quadrant-I (highly resilient). Results from the quantile regression showed that the household's level of resilience in the study area was significantly influenced by education, family size, food-secure months, use of soil and water conservation, and role in the community. Therefore, it is recommended to invest in resilience-building schemes, including sustainable livelihood diversification strategies, promote agricultural cooperatives and enhance extension packages that fit to the specific agro-ecology.

Keywords: Determinants, livelihood resilience, shocks, resilient quadrant, quantile regression, Wolaita *Zone*

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5.1 Introduction

Resilience concept has been highly promoted by scholars, development practitioners and international humanitarian organizations (Walsh-Dilley, Wolford, & McCarthy, 2016) in various topics including climate change, disaster risk reduction and food and nutrition security (Hoddinott, 2014; Alinovi, Mane, & Romano, 2015;Browne, Ortmann, & Hendriks, 2015). Resilience is considered as a uniting policy tool that links humanitarian and development approaches to resolve peoples' chronic vulnerability to recurrent shocks and stresses (Choularton *et al*., 2015). The concept helps not only to design and develop livelihood improvement strategies but also capacity building packages, as well as in integrating climate change adaptation strategies.

Even though the resilience thinking has been increasingly advocated by scholars and organizations, it is not without its limitations, including challenges related its implementation through policy mechanisms (Cooper & Wheeler, 2015) and the fact that it overlooks social or political perspectives of social-ecological systems (Brown, 2014). In this study, livelihood perspective is introduced into resilience thinking to acknowledge the importance of human agency, their rights, and capacities to withstand adverse impacts (Tanner *et al*., 2015), and, specifically, to understand livelihood resilience as a set of capacities (i.e., absorptive, adaptive, and transformative) that enable households and communities to effectively function in the face of shocks and stress, yet achieve a set of well-being outcomes (Smith *et al*., 2015; Béné *et al*., 2016).

Although how to measure resilience remains arguable, some empirical studies have attempted to measure resilience using a composite index as proxy indicators in different contexts, including in Ethiopia (Alfani *et al*., 2015; Alinovi *et al*., 2015; Béné *et al*., 2015; Smith *et al*.,2015; Weldegebriel & Amphune, 2017; Asmamaw *et al*., 2018; Tefera & Kayitakire, 2018). Most of the evidence on livelihood resilience have been produced at the community level and overlook the importance of household-level analysis and its relevance to resilience capacity building initiatives (Alinovi *et al*., 2015; Smith *et al*., 2015; Lindstädter *et al*., 2016; Szoenyi *et al*., 2016).

Empirical studies that have tried to investigate resilience and livelihood resilience at the household levelare found varied in terms of their focus, type of data used and methodologies employed. For example, Vaitla, Tesfay, Rounseville, and Maxwell (2012) investigated resilience and livelihoods change using multivariate models from a biannual panel data set in the Tigray region. The results suggest that significant differences were observed across livelihoods *Zone*s in relation to illness score, assets, social capital, and shock impact. Other empirical studies, including Simane *et al*. (2013) review of building climate resilience in the Blue Nile, Tesso (2017) measured resilience to climate change applying ordinary least squares and censored regression in North Shewa, Weldegebriel and Amphune (2017) explored livelihood resilience in the face of recurring floods using OLS in North West Ethiopia, and Asmamaw *et al*. (2018) assess households' resilience to climate-induced shocks using climate resilience index in the North Central part of Ethiopia. The studies report multiple factors including land type, land size, early warning systems, credit access, education, livestock, income diversification, infrastructure, social capital and culture as significant factors affecting households' resilience level in the studied contexts. On the other hand, few studies employ panel dataset. For example, Asfaw *et al*. (2018) examined the climate resilience pathways of rural households using a composite error model for two waves of panel datasets (2010 and 2011) while Tefera and Kayitakire (2018) applied the Ethiopian Living Standards and Measurement Survey (LSMS) in three waves (2011/12, 2013/14 and 2015/16) for food and nutrition security in Ethiopia.

Though the aforementioned studies have documented key factors influencing households' resilience to shocks, they are geographically limited to central and northern Ethiopia while others focus on national-level analysis using panel data sets. Therefore, none of the evidence from these studies can fully explain the situation in the study area context. Besides, livelihood resilience capacities to climate shock and factors affecting households' resilience level in the study area have not yet been adequately studied.

This paper explains livelihoods resilience index (LRI) through empirical evidence from farm households of three AEZs in Wolaita *Zone*, Southern Ethiopia. The study aims to, a) measure farm household livelihood resilience capacities to climate-induced shocks; and b) explore factors affecting farm households' level of resilience capacities. It will shed light to the livelihoods resilience worksby providing some empirical evidences.

5.2 Methodology

5.2.1 Research design, sampling technique, and data analysis

The study used a quantitative-dominant convergent parallel mixed research design. In selecting representative sample households, a three-stage of sampling procedure was followed. In the first stage, three districts- Damote Gale (highland AEZ), Sodo Zuria (midland AEZ), and Duguna Fango (lowland AEZ)-were selected purposively (Figure 1.8). The criteria for selection include a district with dominant AEZ, vulnerability, demographic and livelihood conditions. In the second stage, following the characterization of the AEZs by Gecho*et al*. (2014a), list of all villages in the selected AEZs were used to further cluster them into the respective AEZs. Hence, a proportional three highland, five midland, and three lowland villages were selected randomly (Figure 1.8). Lastly, a probability proportional to size technique was applied to randomly select 403 farm household heads after a representative size was determined using Kothari (2004). Along with the 403 questionnaire administered to collect socio-economic, demographic, and resilience capacity indicators, 11 focus group discussions, and 15 key informant interviews were concurrently conducted. Quantitative data management and analysis was carried out in Census and Survey Processing System *(*CS-Pro) ®6.3 and Stata®14. A thematic analysis, including description and classification of data, and seeing how concepts interconnect was employed for qualitative information (Bazeley, 2009).

5.2.2 Livelihood resilience index (LRI) calculation

The study uses absorptive, adaptive and transformative capacities (Béné *et al*., 2012; Béné *et al*., 2016) to capture the multidimensionality of livelihood resilience in the face of climate variability and change over drought-prone and vulnerable AEZs in Wolaita, Southern Ethiopia. The three interrelated resilience capacities are at the center of its measurement (Frankerberger *et al*., 2014; Bahadur *et al*., 2015b; Béné *et al*., 2015; Asmamaw *et al*., 2018; Tefera & Kayitakire, 2018).

The dimensions of livelihood resilience are context-specific and systematically combined with equal weighting techniques into three components to get the LRI and then scaled to lie between 0 and 1. This is primarily because, we assume that a household passes as absorptive, adaptive and transformative in a hierarchical manner in the face of adverse climate impacts (Von Grebmer *et al*., 2013). For example, the lower the magnitude of the shock, the more likely the household to be able to repel it successfully, absorbing its impacts without shifting its function, status, or state (Béné *et al*., 2016; Tefera & Kayitakire, 2018). When the shock surpasses the absorptive capacity, then individuals will use their adaptive resilience. The adaptive capacity consists of incremental changes to retain functioning without major qualitative changes in function (Béné *et al*., 2016; Tefera & Kayitakire, 2018). When the incremental changes linked with adaptive capacities are not adequate to protect a household from escaping the adverse impacts of the shock, a more substantial transformation would take place permanently shifting the system in question (Béné *et al*., 2016; Tefera & Kayitakire, 2018).

Although a principal component analysis (PCA) was used to construct the LRI taking the first component as a proxy, the variability explained by the first component (PC1) was very insignificant in this study. Thus, a balanced weight approach was preferred compared to the unbalanced weight approach (Sullivan *et al*., 2002) where each sub-component (indicator) adds equally to the index. In order to offset and address the problems of the PCA, after Tambo (2016) and Asamamaw *et al*. (2018), a composite index was constructed assuming LRI strictly as a positive characteristic for three livelihood resilience capacities. Using a household-level data collected on these indicators, the LRI was computed for each AEZ.

Since each major component is composed of different number of indicators measured on different scales, the standardization was done by taking the functional association between indicators and livelihood resilience (Tambo, 2016). Therefore, the computation of each indicator of the LRI followed the process of standardization used in the life expectancy of the Human Development Index (HDI) (UNDP, 2014) equation 5.1 as:

$$I_a = \frac{Sr - S_{\min}}{S_{\max} - S_{\min}} \qquad (5.1)$$

Where I_a is the standardized value of the indicator a, S_r is the observed (mean) value of the indicator for AEZ r, $S_{\min}$ and $S_{\max}$ are minimum and maximum values of the indicator across all the AEZs, respectively. After each indicator was normalized, the mean value of each major component was calculated using equation 5.2:

$$M_r = \frac{\sum_{a=1}^{n} I_{a_i}}{n} \qquad (5.2)$$

Where M_r is one of the three major components for AEZ r, I_{a_i} is the indicator indexed value by i, which forms each major component and n is the number indicator of each major component. Once values for each of the three major components for each AEZ were computed, LRI was obtained from the weighted average of three of the major components applying equation 5.3:

$$LRI_r = \frac{\sum_{i=1}^{3} W_{m_i} M_{r_i}}{\sum_{i=1}^{3} W_{m_i}} \tag{5.3}$$

Where LRI_r is the livelihood resilience index for AEZ r, W_{m_i} is the weight of major component i, and M_{r_i} the number of indicators of the major component, including adaptive capacity index (ADCI), absorptive capacity index (ABCI), and transformative capacity index (TCI) (Annex 5.4). In line with Tefera and Kayitakire (2018), the study used both the OLS and quantile regression (QR) to estimate LRI and identify factors determining the farm household level of resilience to climate-induced shocks taking the LRI as a continuous dependent variable that ranges between 0 and 1.

5.2.3 Model specification of quantile regression

The analysis applies both the OLS and QR techniques. The standard OLS model specifies the change in the conditional mean of the outcome variable (in our case, LRI) linked with a change in the covariates while the QR model, which is an extension of OLS, specifies changes in the conditional quantiles. The OLS parameters can be estimated by minimizing the sum of the squared errors. This is because the model assures that QR is a finest estimate of the expected conditional mean. On the contrary, the QR acquires parameters by minimizing a weighted average of absolute errors (Koenker, 2005; Arshad, Younas, Shaikh, & Chandio, 2016). The OLS provides only a partial view of the relationship and does not have the capacity to describe the relationship at different points in the conditional distribution of the outcome variable[16]. Therefore, in a QR number of quantiles can be modeled to get a more complete view of how the outcome distribution is influenced by predictors by gaining information about changes in location, spread, and shape (Koenker, 2005; Davino, Furno, & Vistocco, 2013).

Furthermore, the QR is the most appealing regression technique for datasets with variables characterized by heavy-tailed heterogeneous conditional distribution of LRI (Annex 5.1 and

Annex 5.2). Assume now linear quantile regression model with a sample of n observations $\{(\gamma_{i,}\chi_i): i=1,2\ldots,n\}$ where γ_i is LRI and χ_i is $k\times 1$ vector of explanatory variables. Then, the QR model that shows changes in the conditional quantiles as a result of changes in regressors can be specified as (Bulut & Moschini, 2006) in equations 5.1 and 5.2:

$$\gamma_i = \chi'\beta(\tau) + \mu_i(\tau) \qquad (5.1)$$

$$Q_\tau(\gamma_i|\chi_i) = \chi'\beta(\tau) \qquad (5.2)$$

Where χ_i are independent variables; $\mu_i(\tau)$ is the error term that satisfy the quantile restriction $Q_\tau(\mu_i(\tau)|\chi_i) = 0$; $\beta(\tau)$ is a vector of parameters in the vector of regressors that vary with quantiles; $Q_\tau(.)$ is the quantile function defined as the inverse of an underlying conditional (on χ_i) cumulative distribution for γ_i and $\tau \in (0,1)$ is the quantile of interest. The parameter estimates for the τ^{th} sample quantile minimizes the weight of absolute deviations (the errors), that is:

$$\min_{\beta\in R^{\kappa}} \left[\sum_{i\in\{i:\gamma_i<\chi_i\beta} \tau|\gamma_i - \chi_{i\beta}| + \sum_{i\in\{i:\gamma_i\geq\chi_i\beta} (1-\tau)|\gamma_i - \chi_{i\beta}| \right] \qquad (5.3)$$

Where $|.|$ is the absolute value operator and τ^{th} quantile is the maximum value that γ_i can take with a given probability τ. Following others, this study uses τ to take values of 0.10, 0.25, 0.5, 0.75 and 0.90 to see the different levels of farm households' resilience as less resilient, moderately resilient and highly resilient (Tefera & Kayitakire, 2018).These quantiles have also been commonly used in other studies (Bulut & Moschini, 2006; Costanzo & Desimoni, 2017). Then, the probability to observe a value less than the quantile is τ whereas the probability to observe a value beyond that quantile is $(1-\tau)$ .It can be clearly understood from the above specification that the estimation of coefficients for each quantile regression is based on the weighted data on the total sample other than on just a portion of the sample of each quantile (Hao & Naiman, 2007).

Application of QR has a number of advantages compared to OLS in that (i) it is robust against outliers of the regress, (ii) it has efficiency[17]; (iii) it is invariant to any monotone transformation (equivariant), and (iv) it has interpretation benefits over OLS in tracing the conditional quantile at which a particular household lies when a response variable changes

(Koenker, 2005; Melly, 2006; Li, 2015). Another important feature of this model is that it can easily show how changes in the explanatory variables affect the conditional distribution of the LRI, i.e., the probability household to take a specific value in our case (McMillen, 2013). Therefore, conditional QR has been applied in different studies to explain various contexts, including economics (Melly, 2006), ecology (Brennan*et al*., 2015), macro-econometric, financial and environmental analyses (Arshad *et al*., 2016), education (Costanzo & Desimoni, 2017), and resilience to food and nutrition security (Tefera & Kayitakire, 2018). On this account, OLS was first fitted to see the relationship between LRI and the regressors (Annex 5.1 and 5.2). Then, a QR was conducted to estimate the effect of the regressors on LRI at the 0.1, 0.25, 0.50, 0.75, and 0.90 quantiles (Table 5.2 and Annex 5.3).

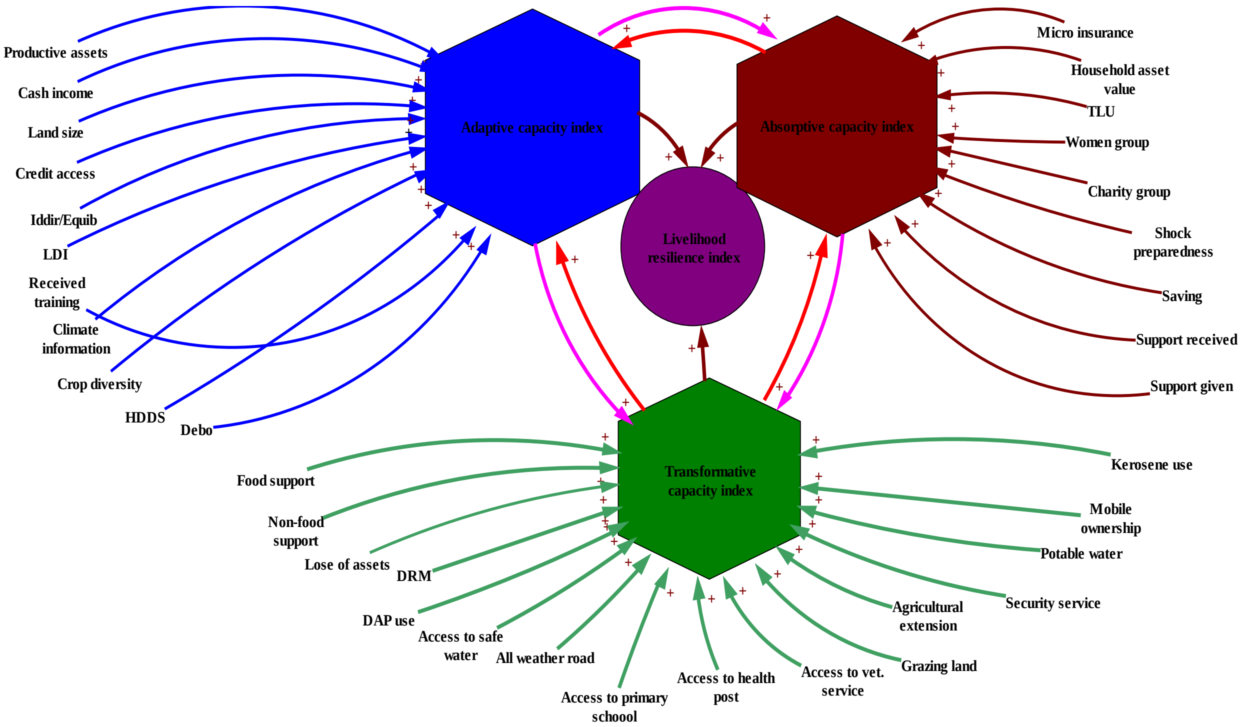

Figure 5.1 Livelihood resilience analytical framework

5.3 Results and discussion

5.3.1 Livelihood resilience capacities

Climate shock and other types of livelihood impoverishments are very common in Ethiopia and disproportionately affect less prepared poor households with different severity levels of impacts across different AEZs. The extent of the loss of livelihoods is further magnified when shocks hit households with differences in resilience capacities simultaneously as in the case of natural disasters and other climatic shocks. To look into the livelihood resilience capacities, their places based differences and explore factors that contribute to different levels of household livelihood resilience, this work derived LRI as a proxy of household livelihood resilience capacities for each AEZ and undertook quantiles based categorization of LRI to group households into different livelihood resilience levels.

Absorptive capacity in climate study is seen as the ability of social systems to absorb and deal with the impacts of climate variability and extremes (Jones, 2017). Frankenberger and Nelson (2013) defined absorptive capacity as the ability to minimize exposure to shocks and stresses (ex-ante) where possible and to recover quickly when exposed (ex-post). The study used 9 variables that collectively form absorptive capacity of households (Figure 5.1). The result shows that a household membership in the women group (0.400), membership of in the charity group (0.360), and support that a household has received from others (0.352) were the top three scoring variables of absorptive capacity in all AEZs (Table 5.1). This agrees with the findings of Asmamaw *et al*. (2018) where social capital was reported as one of the key contributors to absorptive capacity. When comparing the contributions of absorptive capacity forming variables across AEZs, the scores of the contributor variables were diversified.

Table 5.1 Scores of absorptive capacity forming variables by AEZ

		Agro-Ecological Zone			
Capacity	Variables	Highland	Midland	Lowland	Overall
Absorptive capacity index (ABCI)	Household asset value	0.0527	0.0994	0.0474	0.0741
	Tropical Livestock Unit (TLU)	0.2272	0.2931	0.2299	0.2604
	Women group	0.3778	0.4545	0.3217	0.3995
	Charity group	0.4889	0.2323	0.4783	0.3598
	Shock preparedness	0.0333	0.0051	0.0261	0.0174
	Saving	0.2222	0.3939	0.2609	0.3176
	Support received from others	0.3889	0.3586	0.3130	0.3524
	Support given to others	0.3778	0.3030	0.2783	0.3127
	Micro insurance service	0.0333	0.0455	0.0522	0.0447

	Agro-Ecological Zone				
Capacity	Variables	Highland	Midland	Lowland	Overall
	Average ABCI	0.2447	0.2428	0.2231	0.2376

In the highland AEZ, membership of a household in the charity group (0.489), support a household received from others (0.389) and both support a household given to others and membership of a household in a women's group (0.378) dominated absorptive capacity. On the other hand, membership of a household in a charity group (0.478), membership of a household in a women's group (0.322) and support a household received from others (0.313) were found to be the top three contributors towards absorptive capacity in the lowland AEZ. Household membership in a women's group (0.455), households' savings (0.394) and support a household received from others (0.359) were the top three variables yielding absorptive capacity in the midland AEZ (Table 5.1).

Adaptive capacity is the ability of a system to adjust, modify or change its characteristics and actions to moderate potential future damage, and to take advantage of opportunities, all to continue functioning without major qualitative changes in function (Béné, 2013; Smith *et al*., 2015; Tefera & Kayitakire, 2018). Adaptive capacity is comprised of learning and adjusting after a disaster (Bahadur *et al*., 2015b), and therefore, is taken as a crucial factor in achieving resilience at different levels (Frankenberger & Nelson, 2013). Among the 11 important variables forming adaptive capacity (Figure 5.1), *Iddir/Equib* was the main variable that yielded adaptive capacity component scoring weighted value of 0.9 in all the AEZs, followed by household dietary diversity score (HDDS) in the midland (0.485) and participation in *Debo* (working together) in both the lowland and highland (0.60 and 0.522, respectively). Crop diversity (0.433), credit access (0.365) and HDDS (0.376) were found to be the third-highest scoring variables in the midland, lowland, and highland, respectively (Table 5.2). Except for social capitals (*Iddir/Equib* and *Debo),* importance of the other adaptive capacity yielding variables have been claimed by many studies in Ethiopia (Weldegebriel & Amphune, 2017; Asmamaw *et al*., 2018; Tefera & Kayitakire, 2018).

Table 5.2Scores of Adaptive capacity forming variables by AEZ

Capacity	Agro-Ecological Zone				
	Variables	Highland	Midland	Lowland	Overall
Adaptive capacity index (ADCI)	Productive assets	0.038	0.082	0.071	0.069
	Cash income	0.053	0.087	0.061	0.072
	Land size	0.096	0.078	0.093	0.086
	Credit access	0.211	0.298	0.365	0.298
	Livelihood Diversification Index (LDI)	0.231	0.301	0.198	0.256
	Received training	0.244	0.172	0.209	0.199
	Climate information	0.289	0.293	0.339	0.305
	Crop diversity	0.353	0.433	0.217	0.354
	Household dietary diversity score (HDDS)	0.376	0.485	0.316	0.413
	Debo-working together	0.522	0.258	0.600	0.414
	Iddir/Equib	0.900	0.939	0.887	0.916
Average ADCI		0.301	0.312	0.305	0.307

The third resilience component, transformative capacity, deals with the ability of social system to adapt to, anticipate and absorb climate extremes and disaster by adopting transforming policies that basically change the institutional rules of the game (Béné, 2013).

As a capacity, it is linked with the ability to create essentially new systems when the existing ecological, economic and social structures are unsustainable (Béné *et al*., 2012; Tefera & Kayitakire, 2018). Referring to the transformative capacity dimension of livelihood resilience, out of the 16 variables used (Figure 5.1), access to health posts, all-weather roads, veterinary services, safe water, agricultural extension and security services and DAP fertilizer use were the major transformative capacity forming variables with a weighted score value of at least 0.7 in all the AEZs. The only exception was safe water access, which registered a weighted score of 0.357 in the lowland AEZ (Table 5.3). Overall, health posts, veterinary services, and all-weather roads performed well in yielding transformative capacity in the study area, with respective scores of 0.968, 0.943 and 0.856, and their performance in yielding transformative capacity was almost similar across all the AEZs. The contribution of access to basic services to transformative capacity has been evidenced by the empirical literature in Ethiopia (Asmamaw *et al*., 2018).

Table 5.3 Scores of Transformative capacity forming variables by AEZ

Capacity	Variables	Agro-Ecological Zone			
		Highland	Midland	Lowland	Overall
Transformative capacity index (TCI)	Food support	0.111	0.040	0.183	0.097
	Non-food support	0.044	0.081	0.078	0.072
	Lose of assets	0.256	0.364	0.270	0.313
	Disaster risk management	0.178	0.066	0.157	0.117
	DAP use	0.811	0.798	0.835	0.811
	Access to safe water	0.811	0.763	0.357	0.658
	All weather road	0.811	0.990	0.965	0.943
	Access to primary school	0.667	0.449	0.757	0.586
	Access to health post	0.956	0.980	0.957	0.968

	Agro-Ecological Zone				
Capacity	Variables	Highland	Midland	Lowland	Overall
	Access to veterinary services	0.811	0.889	0.835	0.856
	Agricultural extension	0.744	0.773	0.722	0.432
	Access to security service	0.678	0.899	0.722	0.401
	Access to grazing land	0.111	0.247	0.130	0.388
	Access to potable water	0.556	0.485	0.304	0.498
	Mobile ownership	0.378	0.576	0.426	0.500
	Kerosene use	0.000	0.025	0.078	0.183
Average TCI		0.138	0.137	0.125	0.134
Livelihood resilience index (LRI)		0.373	0.390	0.3649	0.3791

Results from the descriptive analysis of livelihood resilience capacities show that the overall average resilience level of households in the study area is 0.379 and resilience capacity differences by AEZ is minimal (0.390, 0.373, and 0.365 for the midland, highland,and lowland, respectively) (Table 5.3).

In terms of resilience components, adaptive capacity dominates all other capacities with an average score of 0.307, followed by absorptive capacity (0.238) and transformative capacity (0.134) (Figure 5.2). This result was consistent with the findings of Weldegebriel and Amphune (2017) and Tefera and Kayitakire (2018) but contrary to the findings of Asmamaw *et al*. (2018) where the leading role of absorptive capacity was revealed. This pattern of contribution of components of household livelihood resilience was also consistent across all

AEZs (Figure 5.2). Contrary to studies by Asmamaw *et al*. (2018) and Tesso (2017), livelihood resilience capacity, in general, and all resilience capacities, in particular, were found to score insignificant difference across the AEZs. Such insignificance difference across AEZs can be attributed to the almost similar adaptive, absorptive and transformative household profiles exhibited across the AEZs (Figure 5.1).

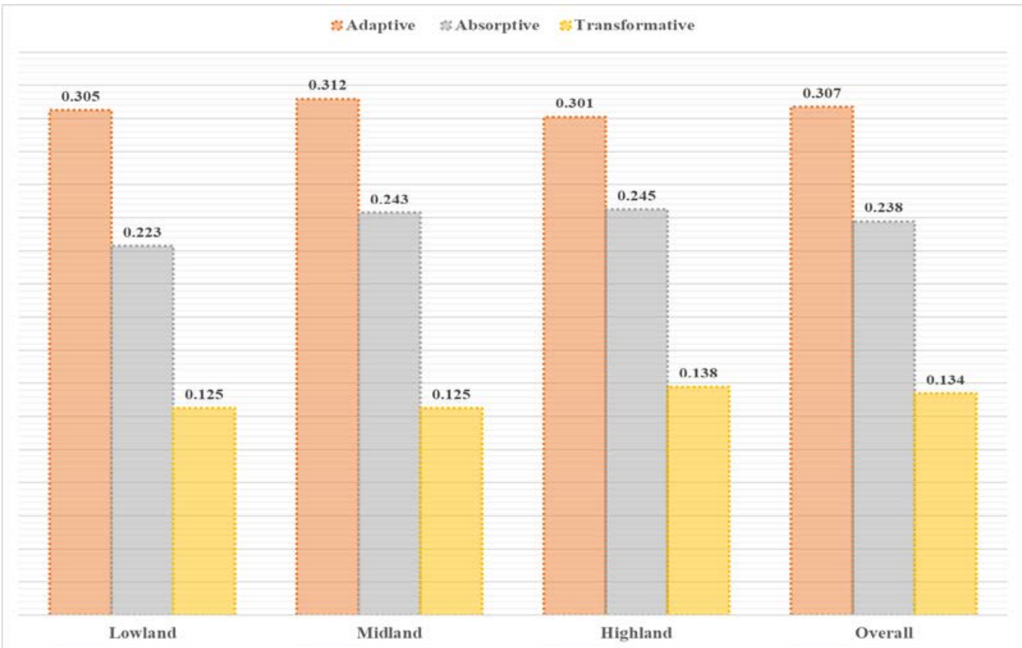

Figure 5.2 Livelihood resilience capacities by AEZ

5.3.2 Subjective resilience capacity indices

In line with Tanner *et al*. (2015) and Jones, Samman, and Vinck (2018), the study computed the subjective resilience capacity index. Past resilience capacity index (PRCI)[18] was computed from retrospectively asked questions regarding past capacities to climate-induced shocks such as drought, flooding, crop failure, and livestock diseases. To develop the future resilience capacity index (FRCI), the same series of questions were asked on shocks that are assumed to happen in the future.

Accordingly, farm households from the lowland AEZ had the highest perceived past resilience capacity index value (0.597), followed by the highland AEZ (0.512), and the midland AEZ (0.373) (Figure 5.3). This implies that those in the lowland AEZ perceived themselves to have prepared in advance to adapt to, absorb and transform from adverse impacts of climate-induced shocks if it happened years back. On the contrary, farmers from the same lowland AEZ perceived that they are capable to withstand any climate-related shock happening in the future. Thus, the average index value accounts for 0.679, 0.603, and 0.594 for the lowland, midland, and highland, respectively. In all AEZs, farmers perceived that they are capable to respond to the likely adverse impacts of climate variability and change. The result agrees with the test of association made between the PRCI and FRCI, which indicates that there is a statistically significant correlation between indices ($r=0.58$, $p<0.05$). In other words, on the one hand, farm households perceived that they had capacities which could have been used to offset the adverse impacts of climate variability and change, and, on the other, they anticipated capacities that can be used if climate-induced shocks happen in the near future. In short, the overall PRCI index value was 0.468 while the FRCI is 0.623 and the paired t-test revealed that statistically significant difference was observed between PRCI and FRCI ($p<0.01$).

There is a discrepancy between indices computed for livelihood resilience capacities (ABCI, ADCI, and TCI) based on the objective measurement and subjective resilience capacity indices (subjective measurement), suggesting that farmers have more perceived capacities than they actually do. In agreement with this, the paired t-test result above signifies that farmers have more anticipated capacity to future shocks than the past shocks, which might be linked with the recent memories of El Niño induced shocks that happened in the area in 2015/2016 compared to the uncertain future. Moreover, the inevitable shocks might have forced farmers to perceive that they will have more capacities (absorb, adapt, and transform) than what is at hand and in the past. This is a key area to be strengthened in order to build their perceived resilience capacities and aspirations in the face of the changing climate across the AEZs.

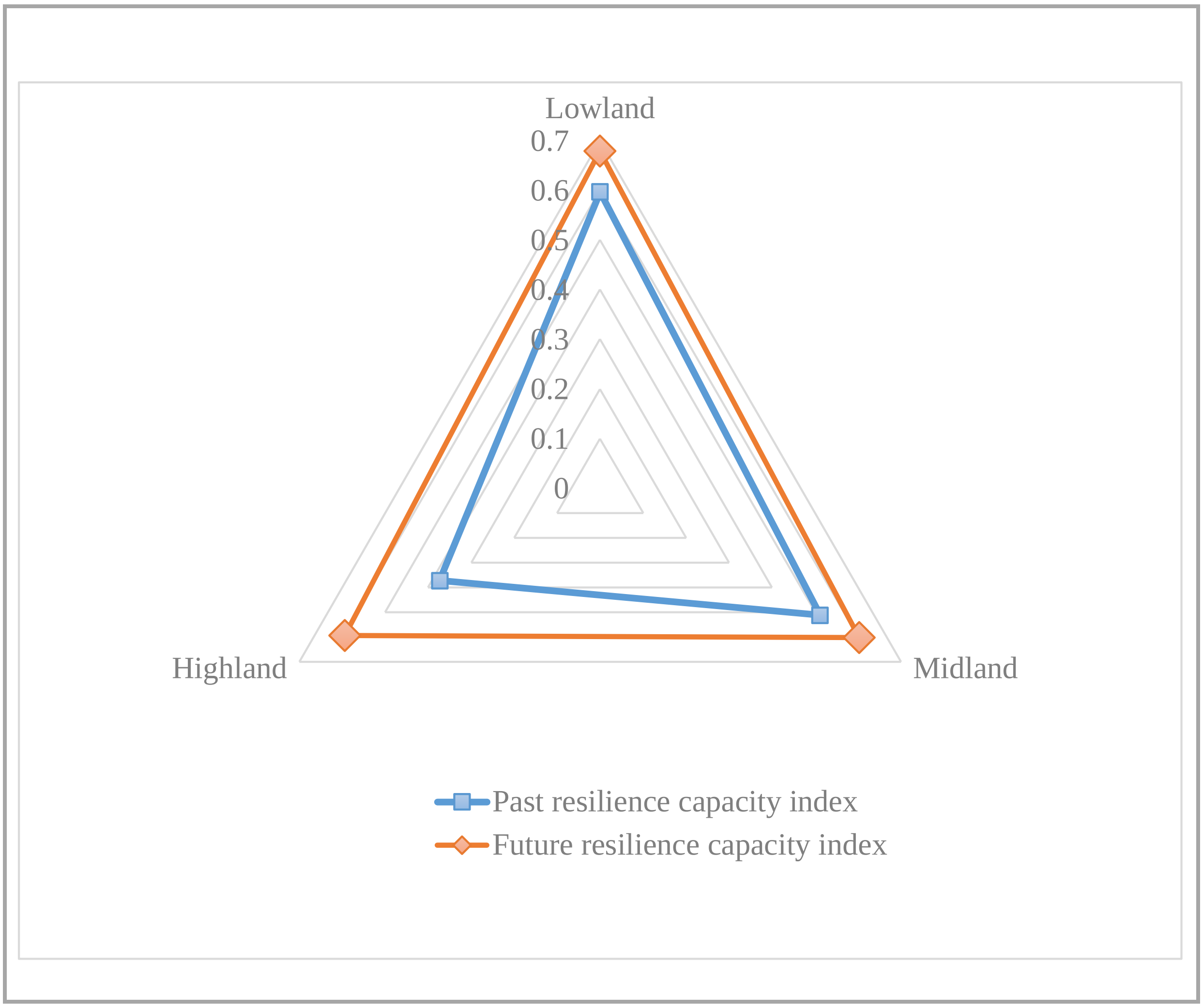

Figure 5.3. Subjective resilience capacity index

5.3.3 Explanatory variables of livelihood resilience index

On average, every household has the livelihood resilience capacity of 0.379 characterized by diversification with varying level of about 28.5 percent and relatively right-sided asymmetry (with 0.11 level of skewness) (Table 5.4). With regard to the LRI determinants, village market distance was characterized by the greatest desperation (about 173 percent) and by relatively high right-sided asymmetry (8.46), with about 30 kilometers of distance at the higher tails of the distribution of LRI. Moreover, household head education, farm experience, and family size were the next in the degree of right-sided skewness, respectively. The only variables which were found skewed to the left were climate shock index and food secure months (Table 5.4).

Table 5.4 shows that the bulk of the surveyed households (80.15 %) engaged in farming as a major livelihood activity. In terms of distribution over quantiles, households with no role in their community, no market information and which did not use soil water conservation (SWC) on their farms were concentrated in the lower quantiles (Q10 and Q25). On the other hand, very few (4.71 %) farm households who were concentrated at the higher tails (Q75 and Q90) had access to irrigation use which signifies their high dependency on rain-fed agriculture making thousands vulnerable to shocks. This is consistent with the proportion of irrigation access that suggests the limited use of irrigation to offset the dependency on the erratic rainfall in the area (Rhamato, 2007).

Table 5.4 Descriptive statistics of the regressors

Continuous Variables	Mean	Q10	Q25	Q50	Q75	Q90	CV	Skewness	Min	Max
Livelihood resilience index	0.379	0.126	0.131	0.376	0.641	0.667	0.29	0.11	0.07	0.755
Farm experience (year)	28.59	2	2	29	62	63	0.46	0.44	2	80
Education (year)	3.63	0	0	3	12	12	1	0.58	0	12
Village market distance (km)	2.87	0.1	0.2	2	30	30	1.73	8.46	0.1	60
Climate shock index (index)	0.72	0.167	0.167	0.75	1	1	0.30	-0.37	0.167	1
Family size (number)	5.94	2	2	6	11	11	0.35	0.40	2	14
Food secure months (number)	7.29	0	0	7	12	12	0.39	-0.13	0	12
Categorical Variable	%	Q10	Q25	Q50	Q75	Q90	CV	Skewedness	Min	Max
Soil Water Conservation (1=yes)	60.05	0	0	1	1	1	0.82	-0.41	0	1
Market information (1=yes)	58.06	0	0	1	1	1	0.85	-0.33	0	1
Access to irrigation use (1=yes)	4.71	0	0	0	1	1	4.50	4.27	0	1
Use of improved seed (1=yes)	38.21	1	1	1	0	0	1.27	0.49	0	1
Main occupation (1=farmer)	80.15	0	0	1	1	1	0.50	-1.51	0	1
Role in the community (1=yes)	67.25	0	0	1	1	1	0.70	-0.73	0	1
Agro-ecology (1=midland)	28.54	0	0	0	1	1	1.02	0.04	0	1

5.4 Quantile regression model and livelihood resilience determinants

Estimated QR models showed heterogeneity of regressors for different LRI quantiles ($p < 0.01$) (Figure 5.4 and Figure 5.5) and differences in goodness of fit for quantiles (Annex 5.3). A total of 8 out of 13 regressors were found to be positively significantly influencing LRI over different quantiles. However, only factors including climate shock index, main occupation (farmers) and distance to the village market affect LRI negatively significantly at different quantiles (Table 5.5 and Figure 5.4). In general, the test for equality of means discloses that a statistically significant difference was observed between and among quantiles for all regressors ($p<0.01$), indicating that the influence of the regressors on the LRI varies from quantile to quantile both positively and negatively. This also supports the explanatory power of the QR over the OLS (Table 5.5).

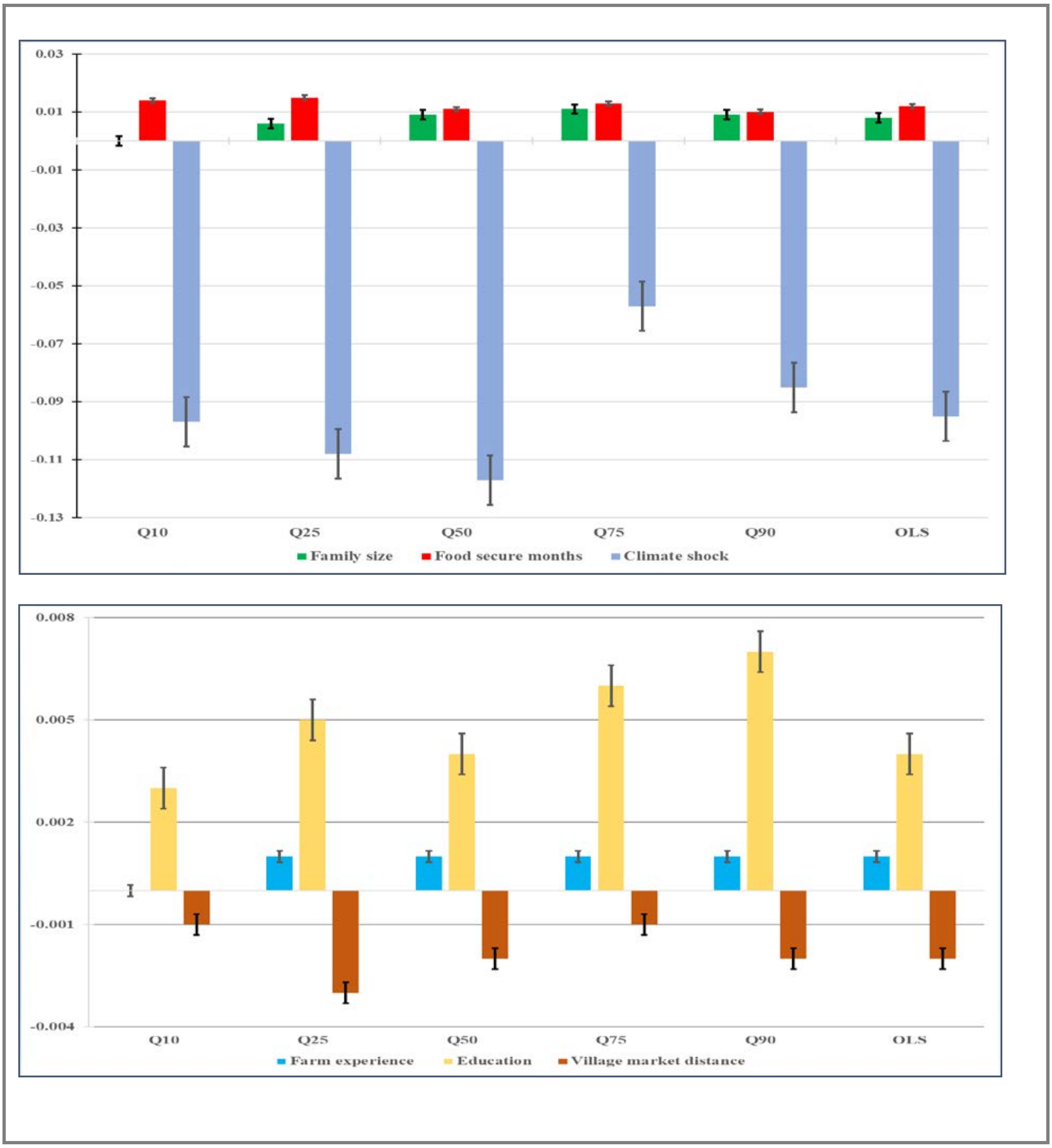

Figure 5.4 Covariate of LRI across quantiles

Regarding the patterns of the regressors over different quantiles, it was evident that the number of food secure months positively significantly affect the farm household's level of resilience across quantiles (p<0.01). At the upper tails, the coefficients for food secure months have slightly and significantly lower effect than the lower tails (p<0.01) (Table 5.5 and Figure 5.4). The results suggest that an increase in the food secure month positively contributes towards the enhancement of households' resilience level while holding the effect of other regressors constant.

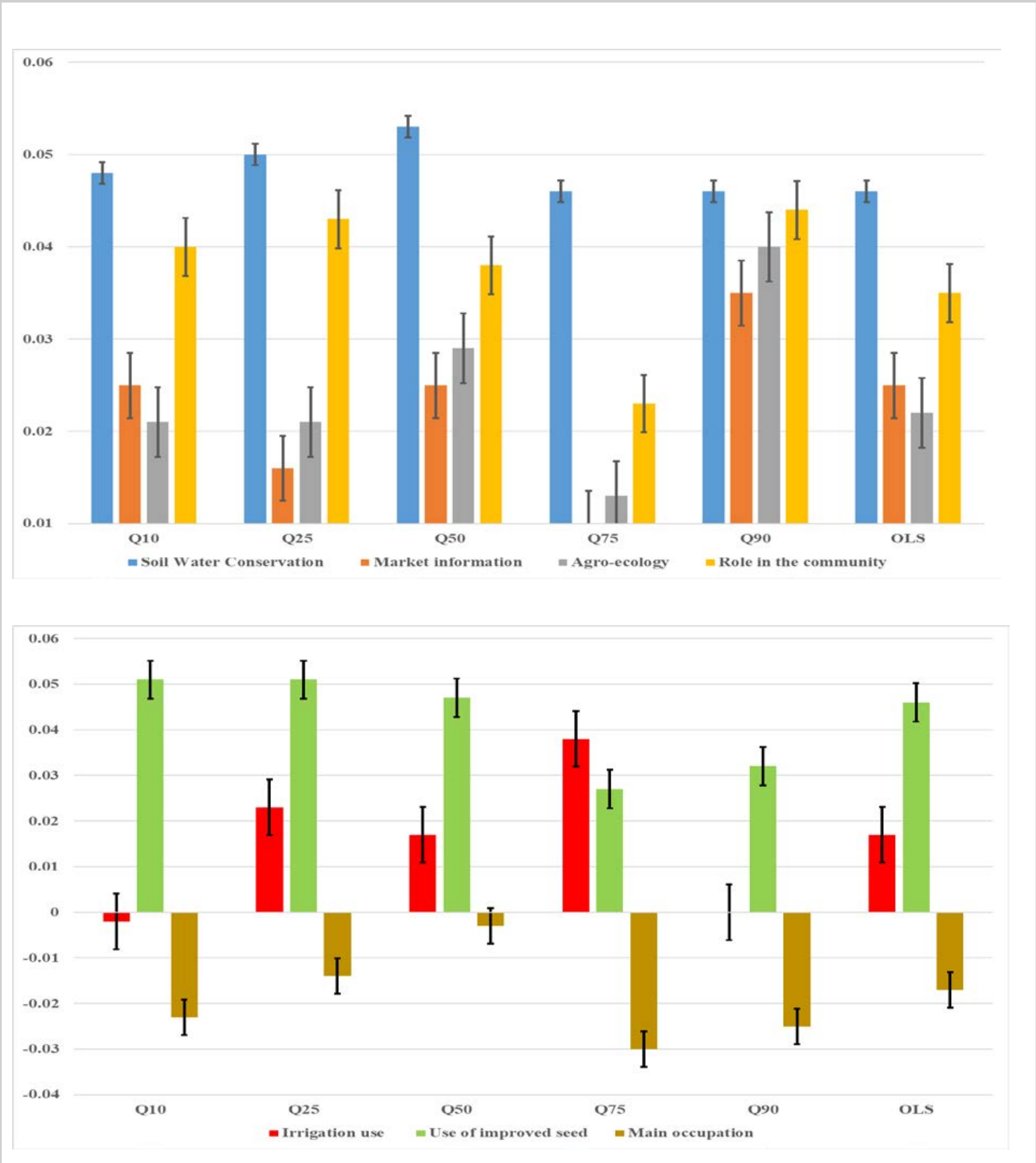

Figure 5.5 Covariate of LRI across quantiles

Another important result that the QR revealed was that education had a positive and significant influence on farm households' resilience level across quantiles. The influence consistently improves from the lower quantile (Q10 and Q25) to the higher quantiles (Q75 and Q90) ($p<0.01$). This effect of education was higher in the upper quantile, which was statistically significant ($p<0.01$), and lower in the lowest quantile ($p<0.01$). The overall mean difference was also statistically significant ($p<0.01$), implying that the role of education increases as we go from the lower to the higher quantiles (Table 5.4 and Figure 5.4). Previous studies reported the positive impact of education on the resilience capacity in Ethiopia (Weldegebriel & Amphune, 2017).

The study area is one of the most degraded parts in Ethiopia (Rhamato, 2007; Cochrane & Tamiru, 2016; Bedeke*et al*., 2018). The use of SWC is one of the mechanisms to improve soil fertility and enhance agricultural production. The test for equivalence of coefficients indicate that estimates significantly differ across the quantiles (Table 5.5) and its effect on LRI slightly increases from the lower quintile to the median (50^{th}) and remains the same both in the 75^{th} and 90^{th} quantile It can be inferred from this that SWC was carried out by farm households in all quantiles owing to its crucial role for the vulnerable farm households in the area (Table 5.5 and Figure 5.5). The result concurs with a recent study by Bedeke *et al*. (2018).

Farm household roles in their respective community have significantly and slightly higher magnitude effect on the 25^{th} and 90^{th} quantiles compared to those in the 10^{th} and 75^{th} quantiles of the LRI distribution (Table 5.5 and Figure 5.5). As a result, the mean differences between coefficients were found to be statistically significant ($p<0.01$), which indicates a varied level of influences of farm household involvement in the community development activities on their level of resilience. The estimates from the QR has shown that the location of the farm households was only significant at (Q25, Q50, and Q90) ($p<0.01$). The results indicate that AEZ (midland) affects positively those in the upper quantile (highly resilient) compared to those in the lower quantile (less resilient households). The result is in agreement with findings from previous studies that reported that AEZ can influence both positively and negatively (Gecho *et al*., 2014a). The results make clear that households having market information were found to take advantage of resilience capacity over those who did not in the lower LRI quantiles. The difference is, however, insignificant in the 75^{th} percentile and 25^{th} percentile (Table 5.5 and Figure 5.5). Though statistically significant, the effect that differences in the influence of access to market information across quantiles has on the distribution of LRI was the same in its magnitude both in the median and 25^{th} quantile (Figure 5.5). Moreover, the result from the use of improved seed has positive and significant effects in all quantiles.

With regard to the effect of family size on the LRI distribution, the result shows that the influence was the same both in the 50^{th} quantile ($p<0.01$) and 90^{th} quantile ($p<0.05$). It was slightly higher in the 75^{th} quantile ($p<0.01$) compared to the 25^{th} quantile ($p<0.05$), suggesting that large family positively contributes to the highly resilient households compared to the less resilient households. The contribution could be in the form of labor force and diversification in the income sources while it may be a burden for those in the lower quantiles (Table 5.5 and Figure 5.5).

Another notable result in the QR was the negative and significant effect of the climate shock index on LRI. It consistently negatively affects LRI in all quantiles with the magnitude of influence being higher in the lower quintile compared to the upper tails. This is because the magnitude declines from the lower quantile to the upper quantile, signifying the effects of climate-induced shock is higher among the less resilient households in relation to the highly resilient households. Although the effect of village market distance on LRI is insignificant in the upper and lowest quantiles, it adversely affected the farm household's level of resilience in the 25th ($p<0.05$) and 50th quantile ($p<0.1$), respectively. This partly implies that the resilient households are those located in close proximity to the village market than those at far distance from the village market center. The significant mean effect of the main occupation (farmer) on LRI was negative and significant only for the median (50th of the quantile distribution), suggesting that being a farmer negatively affects the level of resilience. This is likely due to the association of farming with lack of livelihood diversification strategies (Gecho *et al*., 2014a).

In general, most of the regressors have positively significantly and negatively significantly influence the LRI in the median (50th quantile) compared to the upper and the lower quantile. In addition, the regressors have mixed patterns in terms of affecting the level of resilience. The influences of some of the variables are higher in the lower quantile while higher in the upper quantiles, indicating that the farm household's level of resilience can be influenced by different factors with varying degrees of influences.

In brief, the computed absorptive capacity index of the highland AEZ (0.244), followed by the midland AEZ (0.243), and the smallest was for the lowland AEZ (0.223). The adaptive capacity of the midland was higher (0.312) than both the highland (0.301) and the lowland (0.305) AEZs. In terms of transformative capacity, the highland AEZ (0.138) takes the lead, followed by the midland (0.137), and the minimum was for the lowland (0.125) AEZ. The overall LRI specifies that the midland AEZ stands as a highly resilient EZ (0.390), followed by a moderately resilient highland AEZ (0.373), and the lowland remains as less resilient AEZ (0.365) to climate variability and change-induced shocks.

Table 5.5 Comparison of OLS and quantile regression results

	Quantile Regression						Coef. Test across quantiles
Variables	Q10 (Coef.)	Q25 (Coef.)	Q50 (Coef.)	Q75 (Coef.)	Q90 (Coef.)	OLS (Coef.)	(F value)
Farm experience (year)	0.000 (0.001)	0.001* (0.000)	0.001 (0.000)	0.001 (0.001)	0.001 (0.001)	0.001 (0.000)	498088.8***
Education (year)	0.003** (0.002)	0.005*** (0.002)	0.004*** (0.001)	0.006*** (0.002)	0.007*** (0.002)	0.004*** (0.001)	85021.2***
Village market distance (km)	-0.001 (0.001)	-0.003** (0.001)	-0.002* (0.001)	-0.001 (0.001)	-0.002 (0.002)	-0.002** (0.001)	72719.6***
Soil and water conservation (1=yes)	0.048*** (0.013)	0.050*** (0.012)	0.053*** (0.011)	0.046*** (0.013)	0.046** (0.018)	0.046*** (0.009)	5.45e+06***
Market information (1=yes)	0.025* (0.013)	0.016 (0.012)	0.025** (0.011)	0.010 (0.013)	0.035** (0.018)	0.025*** (0.009)	33714.5***
Agro-ecology (1=midland)	0.021 (0.014)	0.021* (0.012)	0.029*** (0.011)	0.013 (0.014)	0.040** (0.019)	0.022** (0.009)	52229.6***
Climate shock (index)	-0.097*** (0.031)	-0.108*** (0.028)	-0.117*** (0.026)	-0.057* (0.031)	-0.085** (0.042)	-0.095*** (0.021)	223794.1***
Family size (number)	-0.000 (0.003)	0.006** (0.003)	0.009*** (0.003)	0.011*** (0.003)	0.009** (0.004)	0.008*** (0.002)	117251.5***
Access to irrigation (1=yes)	-0.002 (0.029)	0.023 (0.026)	0.017 (0.024)	0.038 (0.029)	-0.000 (0.039)	0.017 (0.020)	64409.7***
Use of improved seed (1=yes)	0.051*** (0.014)	0.051*** (0.012)	0.047*** (0.011)	0.027** (0.013)	0.032* (0.018)	0.046*** (0.009)	321671.2***
Main occupation (1=farmer)	-0.023 (0.016)	-0.014 (0.014)	-0.003 (0.013)	-0.030* (0.016)	-0.025 (0.022)	-0.017 (0.011)	111660.3***
Role in the community (1=yes)	0.040*** (0.015)	0.043*** (0.013)	0.038*** (0.012)	0.023 (0.014)	0.044** (0.020)	0.035*** (0.010)	453837.6***
Food secure months (number)	0.014*** (0.002)	0.015*** (0.002)	0.011*** (0.002)	0.013*** (0.002)	0.010*** (0.003)	0.012*** (0.002)	
Constant	0.146*** (0.040)	0.134*** (0.035)	0.197*** (0.032)	0.238*** (0.039)	0.293*** (0.053)	0.203*** (0.027)	
Observations	403	403	403	403	403	403	
Pseudo R^2/ R^2	0.310	0.284	0.252	0.224	0.226	0.425	

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

5.5 Livelihood resilience quadrants

Following Andersen and Cardona (2013) for livelihood diversification in Bolivia and Weldegebriel and Amphune (2017) for livelihood resilience in Ethiopian context, we constructed farm households' livelihood resilience quadrants to provide a more illuminating representation of studying households' resilience capacities in the face of climate variability and change over the AEZs in the study area (Figure 5.6). The quadrant is constructed using livelihood vulnerability index (LVI) and livelihood resilience index (LRI) on X-axis and Y-axis, respectively. The Y-axis is based on the average value of LRI $\left(LRI_{mean} = 0.38\right)$, which combined ADCI, ABCI, and TCI (Figure 5.1). The X-axis is based on average value of LVI $\left(LVI_{mean} = 0.53\right)$, which consisted of exposure, sensitivity and adaptive capacity (Figure 4.1).

Regarding the resilience quadrant classifications, we used the mean LRI values below and above the threshold value along with the average value of LVI, which splits the quadrant into left and right corridors. The quadrant signifies that farm households falling on the right side of the average LVI values are highly resilient (*Quadrant-I*) $\left(> \overline{X}_{LRI}\, and < \overline{X}_{LVI}\right)$ and less vulnerable households (*Quadrant-IV*) $\left(< \overline{X}_{LVI}\, and < \overline{X}_{LRI}\right)$.

The less resilient (*Quadrant-II*) $\left(> \overline{X}_{LRI}\, and > \overline{X}_{LVI}\right)$ and highly vulnerable (*Quadrant-III)* $\left(> \overline{X}_{LVI}\, and < \overline{X}_{LRI}\right)$ households, on the other hand, are those who fall on the left side of the threshold. The computed LRI ranges from 0.1-0.99 (the minimum being 0.070 and the maximum value stands at 0.76). Accordingly, the quadrant above the LRI (0.379) value is comprised of both less resilient and highly resilient groups of households, and the quadrant below the LRI (0.379) value includes highly vulnerable and less vulnerable households.

Unlike the study by Weldegebriel and Amphune (2017) that reported six quadrants of farmers' livelihood resilience capacities to flood disaster, in this study farm households' livelihood resilience typologies were only four, suggesting the predominance of a highly vulnerable group, on one hand, and the highly resilient households, on the other hand (Figure 5.6). This result agrees with a study by Rahmato (2007) on smallholder farmers in Wolaita which found that they are vulnerable to the unpredictable rainfall which is too much, too little, too early or too late and since the irrigated land in the area was only 0.4%. Besides, the erratic nature of rainfall and series land fragmentation over the decades, agricultural productivity has been exhausted and is unable to support the growing population. Because of this, Rahmato concludes that agriculture in Wolaita "*has exhausted its potential and is becoming increasingly unviable for the great majority*."

Moreover, the proportion of people receiving food aid during different times mirrors this reality in Wolaita (Rahmato, 2007; FAO, 2016a; WZFED, 2017) (Figure 5.6). In 1994, only 17.8 % of the population received emergency food aid (CSA, 1996; Rahmato, 2007). Based on the available district-level data, the proportion involved in the Productive Safety Net

Program (PSNP)[19] that provides support to rural food insecure households, ranged from fourteen to thirty-one percent (Cochrane & Vercillo, 2017).

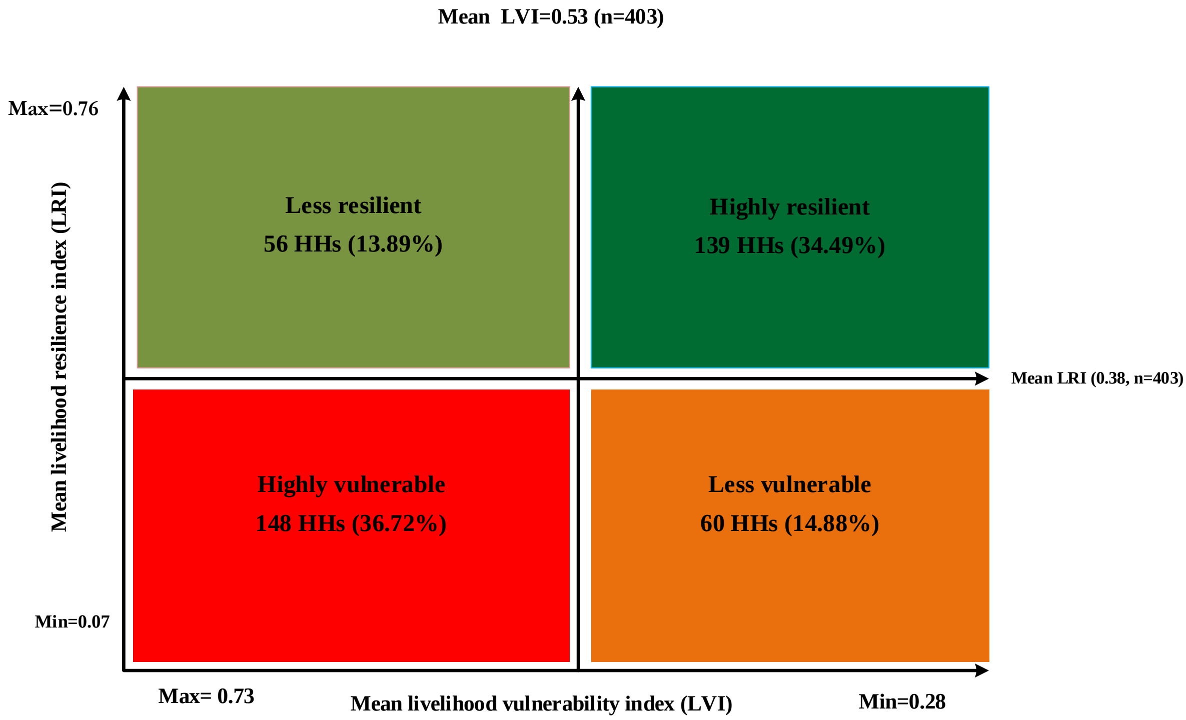

Figure 5.6 Resilience typologies by sampled households

Taking the mean values of both LVI and LRI as thresholds, a total of 148 (36.72 %) were found in the highly vulnerable (*Quadrant-III*). In terms of the proportion of households in each quadrant, the study revealed that 139 (34.49%), 60 (14.88%), and 56 (13.89%) of sampled households are positioned as highly resilient, less resilient, and less vulnerable households, respectively (Figure 5.6). These results also agree with extracts from the qualitative information on the classification of the vulnerable and resilient households across AEZs. The vulnerable households are those who lack livestock, unable to send their children to school, having no ox, no milking cow, not healthy, lack adequate labor to work, landless or limited farmland, food insecurity, members of PSNP, and not using improved agronomic practices among others. On the contrary, the resilient households include farmers with a pair of oxen to plow the land, saving in the banks, adequate food for family or feed from storage, good health and labor to work on fields, and never been dependent on others.

The aforementioned quadrants are instrumental in terms of providing data and critical insights as to where to emphasize the design and development of livelihood improvement and development intervention packages. In view of this, it is important to invest in different and integrated livelihood resilience schemes that can enhance the capacity of highly resilient groups while at the same time can also decrease the number of highly vulnerable groups. Apart from this, it is also imperative to work on enabling the less resilient and less vulnerable households. This is especially relevant since people's vulnerability to the changing climate and the occurrence of extreme events such as floods and droughts are projected to continue in the future (IPCC, 2014; Eshetu *et al*., 2014).

5.6 Conclusion and recommendations

This study analyzed households' livelihood resilience capacities in the face of climate-induced shocks and factors influencing the farm household's level of resilience in three AEZs in Wolaita *Zone* of Southern Ethiopia. Although debates continue regarding resilience measurements due to differences in the resilience components measured, type of data used, methods, level analysis, and other factors this study has developed indicator based livelihood resilience index (LRI) based on a cross-sectional survey data collected from 403 farm households over AEZs in Wolaita *Zone*, Southern Ethiopia. The quantification of resilience capacities was based on three different components namely, absorptive capacity, adaptive capacity, and transformative capacity using combined econometric models-OLS and QR-to capture the multidimensionality of livelihood resilience in the study area context.

The study showed that the overall livelihood resilience capacity level stands at 0.379 with a minimal difference across AEZs. Adaptive capacity takes the lead role while transformative capacity is the least with consistent patterns in all the three AEZs. The computed indices show that social capital-*iddir/equib* is one of the main pillars of adaptive capacity in all the AEZs. Thus, the role of other adaptive capacity forming variables is in agreement with empirical studies in Ethiopia. Similarly, farm households supporting each other and membership in charity groups were the major contributors of absorptive capacity. On the contrary, households shock preparedness, use of microinsurance and household asset values had minimal roles to this particular component. Farmers' access to health posts, all-weather roads, veterinary services, safe water, agricultural extension, security services, and input use were the major contributing factors towards the transformative component in all AEZs.

The quantile regression confirms that the effect of education, soil and water conservation, food-secure months, input use, agro-ecology, role in the community and family size on the level of resilience have varied influences at different quantiles validating the explanatory power of quantile regression over the OLS. However, the negative effect of climate-induced shock is common in all quantiles and the magnitude of influence is higher in the lower quantiles compared to the upper tails.

On the subjective resilience, the study showed that owing to their susceptibility to shocks farmers have more anticipated capacities yet their actual capacities are insignificant. The mapped resilient quadrant located that most of the farm households are highly vulnerable. In terms of AEZs, the midland stands as a resilient AEZ while the lowland AEZ is a highly vulnerable AEZ to shocks. In general, the use of combined approaches, OLS and QR, on one hand, and subjective and objective resilience measurements, on the other hand, yielded robust results that captured the multidimensionality of livelihood resilience and the determinants across AEZs.

Evidence from the econometric models can be used as an important input for the design and development of resilience capacity building schemes such as investment in household asset building programs (HABP), sustainable livelihood diversification strategies, promotion of agricultural cooperatives, and enhancing extension packages tailored to the specific AEZ. It is also imperative to invest in infrastructure and providing improved social services, including improved rural electrification to enhance both adaptive and transformative capacities in the face of inevitable climate-induced shocks while attracting private investment in the agricultural sector and agro-processing industries.

Nevertheless, it should be kept in mind that the study was based on randomly selected 403 farm households representing three AEZs covering 11 villages. Therefore, it is recommended to carry out further research on mapping the livelihood vulnerability profiles and livelihood resilience capacities biannually (hunger and production seasons) covering most of Wolaita. Such mapping is crucial to generate evidence for the planning and implementation of wide-ranging development interventions.

Chapter six

6 Chapter synthesis

6.1 Introduction

Climate variability and change have manifested in different forms, including an increase in temperature, change in precipitation and sea-level rise, intensification of natural hazards such as floods, droughts, and landslides (IPCC, 2007; IPCC, 2014). It is also argued that climate variability and change are inevitable and will increase the frequency, intensity, spatial extent, duration, and timing of extreme weather and climate events (IPCC, 2012). Evidence suggests that the global climate is changing and the rate of change will likely increase impacting human and natural systems (Eshetu *et al*., 2014; IPCC, 2014; Thornton *et al*., 2014). This is the reality in sub-Saharan Africa, including Ethiopia where most livelihoods are dependent on climate-sensitive sectors. Due to this, the region has been recognized as one of the most vulnerable to climate change impacts as evidenced by the irregularity of rainfall (Serdeczny *et al*., 2017).

Various studies have suggested that the Ethiopian climate has changed and the historical trends of climate variability and change confirm these observations. Particularly, Ethiopia's vulnerability to climate variability and change have been linked with its high reliance on the agricultural sector, severe land degradation. high population pressure and low adaptive capacity (Eshetu *et al*., 2014; EPCC, 2015; Simane *et al*., 2016). To respond to these, building livelihood resilience requires reducing exposure and sensitivity while improving capacitates to absorb, adapt and transform from recurring climate shocks. In doing so, assessing farmers' perceptions of climate variability and change, using local level indicators and scrutinizing farmers perceived livelihood capacities to withstand shocks can be of particular interest in the planning and implementation of local-level adaptation strategies. Evidence from empirical studies carried out in parts of Ethiopia reveals many factors contributing to the high level of exposure and sensitivity to climate shocks, and factors that contribute to withstanding the adverse impacts of climate change. Even though Ethiopia is diverse socio-economically, demographically, culturally, and agro-ecologically, a comprehensive studies that document the trends and patterns of mean and extreme climate events, farmers' livelihood vulnerability, livelihood resilience capacitates from the cyclical shocks and factors determining both vulnerability and the resilience levels in the study area context has not adequately been conducted.

Resilience is popular in development studies, including poverty, vulnerability, and food security. Nevertheless, it has been a challenge to find sound measures (Alfani *et al*., 2015; Bahaduri *et al*. 2015) and how to quantify resilience remains controversial (Bene *et al*., 2012). However, many recent studies in measuring resilience have applied complex econometric approaches based on national-level data, integrating different datasets or panel data (Allinovi *et al*., 2015; Bene *et al*., 2015; Smith *et al*., 2015; Tefera & Kayitakire, 2018) at different levels of analysis. Though some studies attempted to study resilience in Ethiopia, the use of rigorous analyses is needed to capture the complexity and multidimensionality of households' livelihood resilience at the local level. Since panel data are unavailable at the local agro-ecological level, it makes panel data-based approach inapplicable.

This study tries to explore households' livelihoodvulnerability conditions to the changing climate and investigate resilience capacities from absorptive, adaptive and transformative perspectives in Wolaita *Zone*, Southern Ethiopia. To this end, it analyzed trends in extreme climate events in three agro-ecological *Zone*s; climate trends and determinants of farmers' climate change perceptions; the livelihood vulnerability of farmers to climate variability and change; and measured livelihood resilience capacities (absorptive, adaptive and transformative) and the determinants of the level of resilience in the three agro-ecological *zone*s.

The study employed a convergent parallel mixed design whereby qualitative approach was used to complement the quantitative approach by which the bulk of the study data was generated. In contrast to the usual way of measuring resilience and vulnerability by using panel data representing the wider geographic scale, this study followed a pragmatic approach of capturing the local level realities that are inherent to the climate change effects and, hence, the study was based on cross-sectional data collected from sampled households in three agro-ecological *zone*s. It also employed gridded meteorological time-series data (1983-2014) representing the three AEZs. On the other hand, the use of micro-level cross-sectional data to measuring households' livelihood resilience capacities at different agro-ecological settings helped to develop multidimensional livelihood resilience index. Thus, this innovative approach is believed to contribute to the methodological debates on livelihood resilience measurement based on cross-sectional data at the local level.

Most of the scientific studies on vulnerability have focused on the regional or national scale (Füssel, 2007; Hinkel, 2011). However, the local level vulnerability analysis is an essential precondition for local-level planning and identification of resilience planning and strategies, particularly to those natural resource-dependent communities, who are vulnerable to the projected climate variability and changes (Fraser *et al*., 2011). Moreover, national-level vulnerability study result cannot help to address the complexity of vulnerability at the agro-ecological level, which is mainly due to a high projection of significant future climate change in Ethiopia (Simane *et al*., 2016).

To fill this gap, this study estimated and mapped out farm households' livelihood vulnerability situations to the changing climate at different agro-ecological settings at the micro-level. Thus, it provides empirical evidence generated from cross-sectional data from three agro-ecological settings and integrated a mix of development theories of vulnerability and resilience using methodological approaches to capture the issues holistically. The conceptual framework of the study, being tailored to the specific context and theoretical basis of this particular study, brings together key components of vulnerability and resilience studies that pervade the literature so far and used by various sources. Hence, it links the vulnerability context, vulnerability to shocks, factors influencing farmers' climate change perceptions, livelihood resilience capacities, factors that affect resilience capacities and pathways of resilience as well as pathways from vulnerability situation. In other words, the LVI approach framed within IPCC was tailored for the agro-ecology specific vulnerability analysis while the livelihood analysis was rooted in the 3-D resilience framework consisting of absorptive, adaptive and transformative capacities.

Cognizant of this, the study has attempted to bridge the theoretical and empirical gaps existing so far due to the obvious limitation of vulnerability and livelihood resilience studies that focused on the macro level and were very much dependent on panel data which were problematic in capturing the micro-level realities considering the agro-ecological variations. Methodologically, the study was established on climate trend analysis methods, including World Meteorological Organization-Expert Team on Climate Change Detection and Indices (ETCCDI) indices, and Non-Parametric-Sen's Slope Estimator and Mann–Kendall's trend tests, Standardized Rainfall Anomaly, and Precipitation Concentration Index. The econometric models employed include Binary Logit, Ordinary Least Squares, and Quantile Regression being complemented by qualitative information to arrive at valid conclusions.

6.2 Major findings of the study

Climate variability and change in a given area can be investigated in different ways. In this regard, the study first attempted to analyze trends in extreme climate events in the three agro-ecological *Zone*s of Wolaita *Zone*, Southern Ethiopia. The study analyzed changes in the indices of extreme temperature and rainfall based on changes in duration, intensity, and frequency of climatic extremes in the lowland, midland, and highland AEZs in the period between 1983-2014.

The study results indicate that over the last 32 years agro-ecological settings in Wolaita have exhibited significantly increasing and decreasing trends in temperature extremes. Regarding trends of change in the temperature extreme indices, the annual maximum value of daily maximum temperature (TXx), the annual maximum value of daily minimum temperature (TNx), and annual minimum value of daily minimum temperature (TNn) have shown significant positive trends between 1983 and 2014, except in the midland AEZ. The rate of change in the temperature extreme indices was very high in the highland and lowland AEZs, which has negative consequences on the lives and livelihood households in these particular AEZs. It was evident that most of the vulnerable, food insecure and limited capacities to deal with the climate impacts are located in the highland and lowland AEZ, which signifies the positive role of location on farm households' livelihoods **(Chapter 4 and Chapter 5).**

The study results also show that the occurrence of warm nights revealed a significant upward trend in all AEZs except the midland where an insignificant increase was observed in the warm nights, while cool nights were consistently decreasing in all AEZs. An insignificant decreasing trend in the frequency of cool days was detected both in the lowland and midland AEZs. On the contrary, it was documented that the warmest nights were significantly increasing across the three AEZs **(Chapter 2; Esayas *et al*., 2018b).** Due to the change in extreme events, it was observed that the farm calendar of both cultivation and harvesting has changed over time.

Wolaita *Zone* is predominantly occupied by a midland AEZ (56 %). However, positive trends in extreme climate have aggravated drought occurrences, crop failure, livestock, and human diseases, which are characteristically problems in arid and semi-arid areas. The highland areas of Wolaita are now facing arduous challenges linked with climate variability and change. One of these challenges is the emergence of Malaria. Thus, the beginning of Malaria could be an indication of a shift in the traditional AEZ.The study results would be timely inputs for agro-ecology specific design and development of development interventions. The overall temperature extreme trends suggest that the warm extremes are increasing and cold extremes are decreasing, implying significant warming in the AEZs.

Regarding precipitation extreme indices, the study has shown that most insignificant trends across AEZs in most of the precipitation extreme indices with no observed statistical difference between 1983 and 2014. The findings are in agreement with various empirical studies conducted on different geographic scales, including Ethiopia. The consistency in the trend results is revealing of the changing nature of the extreme climate, in general, and the robustness of the WMO indices in explaining the local climate variability and change, in particular. Therefore, results from extreme event analysis could be informative for the design of integrated early warning systems and improvement of planned adaptation strategies at local level linking the meso-macro-level evidence in the face of the changing extreme climate events.

Following the extreme event analysis, the study examined the mean climate trends over the three AEZs employing gridded dataset on an annual time scale. In **Chapter 3,** the study also assessed farmers' perceptions of climate variability and change to identify socioeconomic, demographic, and environmental factors influencing farmers' perceptions. This is important because understanding farmers' perception levels and the several adaptation strategies individual households apply could help to gather complementary information relevant to policy intervention and to tackle the recurring challenges of climate variability and change. Broomell *et al*. (2015) also argue that perceived personal experiences can affect climate change belief and the corresponding adaptation and mitigation measures to be taken. The mean climate trend analysis revealed that the studied AEZs experienced changes in the maximum and minimum temperature during the last three decades. It was documented that the rate of change in the minimum temperature is consistently faster than the maximum in all AEZs **(Chapter 3; Esayas *et al*., 2019).**

Like in many empirical studies in Ethiopia, a non-significant declining trend was observed in the annual total rainfall. However, the midland AEZ has exhibited a significant upward trend in the annual total rainfall (10 mm/year). This could be one of the reasons for the erratic nature of rainfall patterns observed in different parts of Ethiopia. Niles *et al*. (2015) have suggested that special attention should be paid to assessing farmers' climate change perception. Given this, the study has examined farmers' perceptions of climate variability and change. Accordingly, over 60 % of farmers perceived increasing temperature and decreasing rainfall in all AEZs.

Most previous studies focus on the mean climate trend analysis either based on station data or downscaled data with limited attention to the comparison of farmers' perceptions of climate variability and change with the meteorological data. Unlike the previous studies, this study has applied binary logit to identify factors that influence farmers' climate change perceptions in the respective AEZs and compared their perceptions with the newly-promoted gridded meteorological dataset (**Chapter 3; Esayas *et al*., 2019).**

In the study area, agro-ecological *Zone*, sex of the household head, non-farm participation, food secured months, and distance to the village market reduce farmers' perceptions of climate variability and change. On the contrary, farmers' climate change perceptions have been positively influenced by their access to climate and market information, use of the improved seed, training, and education (**Chapter 3; Esayas *et al*., 2019).** Even though the farmers' perceptions about the changes were based on local climatic factors, the study is conclusive that their perceptions are consistent with the scientific meteorological analysis. On top of this, we observed consistent and complementary results between the extreme climate events **(Chapter 2; Esayas *et al*., 2018b)** and the mean climate trends/climate variability and farmers' perceptions **(Chapter 3; Esayas *et al*., 2019),** whichcould be a key indicator of the changing nature of the climate in the study area over the last three decades. Therefore, the empirical evidence presented in this study can have a significant implication for policymakers and local planners to enhance farm households' capacity by providing timely weather and climate information along with informal education programs to improve the skills and literacy level of the vulnerable farmers.

Based on the two chapters **(Chapter 2; Esayas *et al*., 2018b and Chapter 3; Esayas *et al*., 2019),** we have evidence to argue that farmers of the study area have been vulnerable and impacted by climate variability, and change-induced shocks such as droughts, floods, crop failure, livestock and human diseases, which together put lives and livelihoods at risk over the last decades. Once we established the changing nature of the local climate over three decades, the study assessed agro-ecology specific livelihood vulnerability of farmers to climate variability and change **(Chapter 4).**

The study area is characterized by high fertility leading to population density, severe shortage of farmland, impoverished livelihoods, high level of migration outflow, low-level of rural livelihood diversification, limited resource endowments, extreme poverty and chronic food insecurity (Rhamato, 2007; Jufare, 2008; Eneyew &Bekele, 2012; Gecho, 2017; Tantu *et al*., 2017; Gazuma, 2018; Bedeke *et al*., 2018; Esayas *et al*., 2018a, b). These realities coupled with climate variability and change-induced shocks put lives and livelihoods at risk. On this account, the study revealed that the livelihood vulnerability of farm households was considerably influenced by exposure, including climate variability and change, natural disaster, sensitivity, such as agriculture and land use and sustainability, and adaptive capacity, including wealth, technology, infrastructure, knowledge or skills, livelihood strategy, socio-demography, and social networks**(Chapter 4).**In terms of agro-ecological variations, the lowland has relatively higher exposure and sensitivity to climate shocks with a comparatively limited adaptive capacity. The highland AEZ remains moderately vulnerable to climate-induced shocks. On the contrary, the midland agro-ecology experiences the lowest vulnerability with relatively lower perceived exposure and higher adaptive capacity. Acknowledging that the customized LVI-IPCC vulnerability framework is a versatile framework that captures the complexity and multidimensionality of livelihood vulnerability in the study area, which was apparent in different contexts with varying level of exposure, sensitivity, and capacity to adapt the adverse impacts of climate variability and change-induced shocks.

Given the exposure, sensitivity, and adaptive capacity differences between the lowland and midland AEZs of Wolaita, the specific interventions that may demand for policy consideration include strengthening early warning systems and disaster risk management, and encourage the practice of climate-smart agriculture such as dissemination and use of drought-tolerant varieties, improved breeds, weather-indexed insurance, and agroforestry among others **(Chapter 4).**

In previous studies, resilience was taken as a flip side of vulnerability (IPCC, 2001), which obscures farming communities' capacity to absorb shocks, adapt to persistent shocks, and the capacity needed to fundamentally shift in the livelihood in the continued climate shocks (Béné *et al*., 2012; Béné *et al*., 2016; Tefera & Kayitakire, 2018).Unless farmers' extent of vulnerability from exposure, sensitivity, and adaptive perspective are not thoroughly examined, it would be difficult to tackle the context-specific adverse impacts of climate variability and change(Cutter, 2016). Accordingly, the livelihood vulnerability assessment presented in **Chapter 4** served as an entry point to explore farm households' livelihood resilience capacities and factors influencing their level of resilience in the face of increasing climate shocks. As Bahadur *et al*. (2015a) argued, one of the core targets of the sustainable development goals is the focus on resilience with a target to "*build the resilience of the poor and those in vulnerable situations, and reduce their exposure and vulnerability to climate-related extreme events and other economic, social, and environmental shocks and disasters*" *by* 2030(p. 2).

In the study area, farm households' livelihood resilience capacities were substantially influenced by absorptive capacitiessuch as membership in a charity group, support received, and support given to others. It is reasoned that when the shock surpasses the absorptive capacity, then individuals will use their adaptive resilience (Béné *et al*., 2012; Béné *et al*., 2016; Tefera & Kayitakire, 2018). Thus, the adaptive capacity of farmers in the study area was mainly explained by social capital-*iddir/equib*, credit access, working together-*debo*, and crop diversity **(Chapter 5).** It is also argued that households can permanently shift when the incremental changes linked with adaptive capacities are not satisfactory to protect a household from escaping the adverse impacts of the shock (Béné *et al*., 2016; Tefera & Kayitakire, 2018).In the study AEZs, transformative capacity was largely influenced by farmers' access to the health post, all-weather roads, veterinary services, safe water, agricultural extension, and input use. More importantly, we developed resilient quadrants for the study area where 148 (36.72 %) of the households were in the highly vulnerable group and 139 (34.49%) of households were found in the highly resilient category, inferring the limited livelihood capacities of the farmers' in the study area context **(Chapter 5).**

In this study, we documented that household heads education, soil and water conservation, food-secure months, input use, agro-ecology, role in the community, and family size were the major determinants of households' level of resilience. These factors have varied influences at different quantiles confirming the better explanatory power of quantile regression over the ordinary least square. We established farmers' subjective resilience capacity indices and due to their susceptibility to future shocks, farmers have more anticipatory capacities than the actual one **(Chapter 5).** Spatially, those in midland AEZ were found to be resilient compared to farmers of the lowland AEZ who remain highly vulnerable to shocks. The highland AEZ remains moderately resilientto climate-induced shocks. Therefore, results from the econometric models can be used as relevant information for informed policy decisions regarding the various livelihood resilience capacity building initiatives.

6.3 Conclusions

Ethiopia is one of the countries that face the adverse impacts of climate variability and change and often labeled as one of the most vulnerable to climate shocks. The few available studies have focused on national, regional, and sub-regional levels and are confined to a limited geographic area. Added to this, quantitative information on the extent and trends of climate extreme events and climate variability at the local scale that can enable the planning and implementation of local-level adaptation strategies are negligible.

Agro-ecological *zone*s of the study area exhibited increasing trends of warm extremes and decreasing trends of the cold extremes. The inter-annual variability among AEZs consists of both warm and cool years during the 32 years, with the recent years being warmer compared to the earlier ones. The general warming trend sensed in the study area agrees with empirical studies reported both at the national and the local levels. Farmers of Wolaita *Zone* have suffered from the adverse impacts of climate variability and change over three decades. Hence, farm households are increasingly becoming aware of local climate change.

The study concluded that farmers' perceptions of climate change mirror the meteorological analysis though their perceptions were based on local climate factors. Based on the results, it can be inferred that the most vulnerable and less resilient households are located in the lowland AEZ, while the better off and resilient households are those in the midland AEZ. The highland AEZ rests as moderately vulnerable and possesses the modest livelihood resilience capacities to offset the climate-induced shocks. Therefore, it can be said that sampled farmers have limited adaptive capacity over absorptive and transformative capacity, which are lacking across AEZs and thus households remain more vulnerable to adverse impacts of climate variability and change.

The findings of this study can be immensely useful for policy planning and implementation in a context where climate variability and change-induced shocks are becoming serious challenges for policy planners, executors and aid agencies in the context of Wolaita *Zone*, in particular, and Ethiopia, in general. Besides the significance of agro-ecology based evidence generated by this study, use of gridded dataset can be a significant contribution to similar future studies signifying an added merit over the customary use of the station-based data, which often poses a challenge of inconsistency, measurement errors, missing data, and incompleteness. The use of gridded data, as practiced by this particular study, helped to get a complete dataset, allowing easy extrapolation and ensuring the robustness of the data analysis which further led to valid conclusions.

Unlike the usual trend of studying mean temperature at national, regional, and sub-regional levels, this study has explored the extreme temperature in the three AEZs, studied rainfall trends and developed extreme rainfall indices by looking into the spatial and temporal effects. Spatially, the differences and similarities were explored among the three agro-ecologies, and temporally it has shown the long term trends from 1983-2014. Moreover, the use of WMO indices in the context of the study AEZs through checking its appropriateness and robustness can be regarded as a unique contribution in the field of study.

Peculiarly, the study captured the changing trends and perceived impacts of climate change by combining gridded data with the perceptions of the local communities to guide sound and palatable policy decisions. Therefore, the findings of this study and the overall methodological approaches and techniques applied to the study have unique features and their contributions in this growing field of study in the context of Ethiopia, in general, and in particular, are significant. It can be said that the application of a tailored, wide-ranging livelihood vulnerability indicators confirms the soundness of the IPCC vulnerability framework in explaining local level vulnerability conditions to climate variability and change. In general, multiple approaches in a single setting, OLS, and QR on one hand and subjective and objective resilience measurements on the other, produced robust results that captured the comprehensiveness of livelihood vulnerability and livelihood resilience capacities across AEZs, which can be further replicated in similar contexts.

As established by the findings from the analysis of the four objectives, the changing trends in climatic conditions as well as its variability across agro-ecological *Zone*s has yielded a consistent result with the existing body of empirical knowledge in the area while the findings can be regarded as a wake-up call for local-level planning in such areas like Wolaita *Zone*, which has often been the recipient of humanitarian aid due to the impact of long-term environmental and livelihood deterioration exacerbated by climatic variability and population pressure.

6.4 Contribution of the study, policy implications, and future research areas

6.4.1 Contributions of the study

As the study has dealt with the issue of climate variability and change-induced shocks which is among the topmost policy priorities in countries like Ethiopia, where millions of lives and livelihoods have been jeopardized because of lack of empirical evidence that guides policymakers and implementers towards the right choices and decisions. Thus, this particular study is believed to have a significant contribution empirically, conceptually, theoretically, and methodologically.

Conceptually: the study has contributed towards clarifying, refining, and contextualizing the concept of livelihood resilience which has often been open to misconceptions and misinterpretations. It also shed light on livelihood resilience and resilience capacities, emphasizing three different types of capacities (absorptive, adaptive, and transformative) required for vulnerable communities to withstand climate change effects. Moreover, it attempted to elicit the understanding of resilience both objectively and subjectively, which has often been understood merely from the top-down-objective perspectives at the higher or community level. By the same token, as it has often been the case, studies have usually dealt with the concept and measurement of extreme climate. However, this study has brought together and measured both extreme and mean climate, as a better way of understanding climate variability and change in the study area.

Theoretically:the study has made use of a combination of a livelihood vulnerability index, adapting the IPCC vulnerability framework consisting of exposure, sensitivity, and adaptive capacity, and the livelihood resilience index; customizing the 3D-framework, including absorptive, adaptive, and transformative capacities and other theories. Hence, the study tested whether they work in the context of the study area, in particular, and in Ethiopia, in general.

Methodologically: the use and application of WMO indices at a micro-level by checking the robustness of the indices or methodologies, can be regarded as a new insight towards the methodological advance in this theoretically and methodologically conservative area of study in which the WMO indices were usually applied for macro-level studies only. As applied in this study for the first time, the use of a 4 km by 4 km gridded dataset as an alternative view on the use of such dataset in the context where finding downscaled data or complete station based is challenging. To this end, it is a unique contribution of this study, to the growing and least studied theme of the study, i.e., extreme climate both at a wider and local scale. On top of this, the combined way of studying extreme and mean climate in a single study area context to get the complete picture of the climate variability and change in the studied AEZs at this particular sub-regional states of Ethiopia using a newly prompted dataset can be regarded as of immense methodological value addition.

Unlike most of the previous studies that focus on either mean climate trend or econometric modeling based on survey data, this study is exceptional in assessing the mean climate using gridded time series data over the AEZs. It also applied an econometric model to identify factors affecting farmers' perceptions of climate change over AEZs while comparing the meteorological trend analysis with the farmers' perceptions. This methodological input can be taken as a particular value-added to the field.

Another methodological contribution of the study is the investigation of the livelihood vulnerability and livelihood resilience capacities. Following Cutter (2016), exploring both livelihood vulnerability and livelihood resilience at this particular sub-regional state of Ethiopia and over the three AEZs is the first of its kind. Besides these, the quantification and classification of resilience and vulnerability quadrats using LRI and LVI employing the cross-sectional data. It also measured livelihood resilience both objectively and subjectively while exploring it from the direct and indirect measurement point of views as suggested by FAO (2016b), Tanner *et al*. (2015), and Jones *et al*. (2018). On this account, this study is unique among the few available studies in Ethiopia and elsewhere, which may require further verification and validation at a wider scale.

It is also worth mentioning that the study has made an extension and modification of LVI components in the study AEZs, and introduced combined econometric models (OLS and QR) into the socio-ecological thinking such as livelihood resilience. This has extensively been applied in other fields of studies such as ecology (Brennan *et al*., 2015), microeconomic and financial analyses (Arshad *et al.,* 2016), education (Costanzo & Desimoni, 2017) and resilience to food and nutrition security (Tefera & Kayitakire, 2018). The uniqueness stems from the application of OLS and QR in a single issue to capture the multidimensionality of the concept of livelihood resilience, on one hand, and address the weakness of a single model, on the other. On top of these, the need for cross-sectional data and quantification of LRI using OLS and QR models can serve as stepping stones for further studies in a similar context and elsewhere.

Empirically: for this rapidly growing and least studied field of study, measuring livelihood resilience in combination with households' vulnerability to climate-induced shocks. Measuring extreme climate in combination with mean climate by capturing the perceptions of vulnerable communities and developing the measurement indices of LVI and LRI over AEZs can be regarded as a significant empirical contribution of this study.

6.4.2 Policy implications

This Ph.D. research has some significant policy implications. The major policy suggestions include,

⇒ Since this study has generated empirical evidence on climate extreme events during the last three decades over agro-ecological settings of Wolaita, it is thus suggested to use the evidence in the designing, planning, and implementation of agro-ecology specific livelihood improvements schemes, including farm diversification, autonomous, and planned adaptation strategies.

⇒ The documentation and dissemination of climate information and the disaster risk management have to go parallel, which would enhance the farmers level of awareness on climate variability and change while managing the likely occurrences of the climate-induced inevitable shocks. In doing so, it is good to renovate the documentation and dissemination channels of climate information through local media (*Wegeta* FM radio), newspaper, leaflets, seasonal calendar, and church meetings among others.

⇒ It is of relevance to strengthen the early warning system linking with the traditional practices of rainfall prediction. To materialize this, it would be good if the intervention packages are connected with the agriculture and health extension schemes at all levels of governance to increasing the reachability of the services.

⇒ The study identified that lack of agricultural inputs, lack of market linkages, and limited credit access were among the factors determining the farm households level of perceptions in different agro-ecological settings. Therefore, to address the problems, the provision of agricultural inputs, initiating agricultural cooperatives, input and outputs markets or outlets across agro-ecology has to be worked out. Besides, institutional supports such as providing credit services for viable livelihood diversification strategies and connecting the agricultural products with the feasible market outlets must be taken on board by the concerned government offices at local levels.

⇒Capacity building trainings for development agents, health extension workers, farm households (crop diversification and management, livestock and grazing management, livelihood diversification or entrepreneurship, early warning and disaster risk management, afforestation and reforestation of the degraded lands, prevention of the deforestation and degradation, conservation of natural forest and biodiversity) among others must be provided. The training can be delivered collaboratively by the Office of Agriculture and Natural Resources of each *Woreda*, locally deployed NGOs, and higher education institutions operating in the study area context, in general, and on the themes of the training, in particular.

⇒The study results suggested that farmers' high exposure and sensitivity to shock were associated with their high dependency on livelihoods that are sensitive and limited adaptive capacity across agro-ecological settings. Hence, encouraging farmers to use drought-tolerant varieties, high yield crops**,** rear small ruminates, practice small-scale irrigation and water harvesting, agroforestry and sustainable land management **(***i.e., reducing factors contributing to high exposure and sensitivity*) while enhancing adaptive capacity through (livelihood diversification in productive sectors and reduce non-productive investments (funeral, wedding, graduation, and others), which can be useful for farm households in all AEZs.

⇒Factors contributing to a higher absorptive, adaptive, and transformative capacities should be considered in the designing, planning, and implementing livelihood improvement packages in all AEZs. One of these could be creating job opportunities for the unemployed youth through establishing fish farming cooperatives in the newly created artificial Lake in the Omo-Gibe River.This can be materialized with the technical supports from the agricultural research institute and Universities in the nearby areas.

⇒Given most of the surveyed *Kebele*s are highly degraded and fragmented, the need for integrated natural resource management will be crucial not only to respond to the changing climate but also contribute to the restoration of the degraded lands and/or ecological resilience. In doing so, it is imperative to augment the existing best practices of soil and water conservation initiatives being undertaken in the study areas, which can be employed for farm households in all AEZs.

⇒One of the critical challenges in the Zone is what Rhamato (2007) regarded as "micro holders" which are highly vulnerable to flood disaster. The need for resettlement within the same Zone is crucial as it will ease the pressure in densely populated areas and move people to the sparsely populated areas in the peripheries which are irrigable and fertile for cash crop production. It is also vital to introduce and promote farming of adjacent lands in groups which can contribute to reducing land fragmentation and improving agricultural input use, which is feasible to apply in the lowland AEZ. Even though the previous experiences of resettlement programs have been criticized for many reasons, resettlement of farming households to other spacious Zones can still be helpful to support those living in densely populated, highly degraded and steep slope areas of Wolaita Zone.

⇒By promoting forestry, the best practices of the Humbo carbon trading projects (model carbon trading project following the clean development mechanism approach) can be scaled up across other *Wereda*s which has many co-benefits of climate change adaptation and mitigation. There is a need to make a planned shift from productive safety net (PSNP) to household asset-building program (HABP) as part of a 'cargo net approach' (Weldegebriel & Amphune, 2017), which applies for farm households in all AEZs.

⇒Since Wolaita is one of the most densely populated areas in Ethiopia with high internal migration, it is imperative to invest in viable livelihood diversification strategies and/or farm diversification specific to each AEZ, which would not only accommodate the unemployed youths but also contribute to boosting the income of micro and smallholders. In doing so, it is advisable to partner with agricultural cooperatives and microfinance institutions for easy access to financial services and enhances their adaptive capacity.

⇒Finally, since most of the surveyed, households were found to be food insecure with a proxy indicator (household dietary diversity score), it crucial to organize humanitarian assistance to provide both food and non-food support in critical times like the 2015/2016 El Niño induced drought while promoting the establishment of early warning system and disaster risk reduction offices at all levels of administration.

6.4.3 Further research areas

This study was limited in scope and assessed only farm households in three districts covering 11 villages. Therefore, it would be good if further research is undertaken on mapping the vulnerability profiles and resilience capacities covering most parts of Wolaita which will be relevant to design evidence-based innovative development interventions. Exploring farmers' climate change adaptation strategies and factors influencing adaptations is the other key future research area. Assessing climate-smart practices, opportunities and challenges would be the other research area that can be carried out in the agro-ecological settings of Wolaita. Analyzing the retrospective and prospective climate change and linking them with farmers' perceptions of changes covering a wider geographic area is another possible research area. The need to combine both gridded and downscaled data over AEZs to see the correlation between the datasets while linking it with farmers' perceptions of climate variability and change in the study area and elsewhere can also be an area for further research. Moreover, there is a need to collect and analyze biannual panel data regarding livelihood vulnerability and livelihood resilience using production and hunger seasons; to identify the vulnerable, resilient, and in between across time and space.

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Annex 1.1Household survey questionnaire

School of Graduate Studies

College of Development Studies

Center for Environment and Development

Introduction and consent

The purpose of thisHSQ isto explore households' vulnerability situations to the changing climate and investigate resilience capacities from absorptive, adaptive and transformative capacities perspectives in Wolaita *Zone*, Southern Ethiopia. This is, therefore, to collect detailed information on households' vulnerability situations and explore the existing resilience capacities in the face of the changing climate. You are selected randomly for this survey and your participation is based on your willingness to take part. Therefore, your kind cooperation with honest responses to the HSQ will be vital for the overall success of the study. It is purely for academic purpose; results and any other details will not be used for unintended purpose. To this end, anonymity and confidentiality of our respondents are highly guaranteed unless and otherwise under mutual agreement between the concerned parties.

General instruction for the interviewer/enumerator

⇒ Pleaseput the code chosen by the respondent in the space provided for some of the close-ended questions and encircle the chosen response for those which do not have space to put the codes;

⇒ The respondent can choose more than one response for some questions (multiple response items);

⇒ Skip the code to which it does not require the response;

⇒ Write down the response for open-ended questions whenever the respondent provides and necessary;

⇒ Respondent agrees to be interviewed Respondent does not agree to be interviewed

...1 .... 2 → END

↓

MODULE 1: HOUSEHOLD IDENTIFICATION

N	Date of the enumeration:	Time: Start: Finish: _
1.1	HH identification number:	
1.2	*Wereda*: 1=Sodo Zuria 2=Damote Gale 3=Duguna Fango	
1.3	*Kebele*:	
1.4	Village/Gotte____	
1.5	Agro-ecology type: 1=Highland 2= Midland 3=Lowland	
Enumerator name: _______________		**Signature: ______________**

MODULE 2: BASIC DEMOGRAPHIC INFORMATION

2.1 Relation to the head [**code 1**]	**2.2** Age in years (write years)	**2.3** Sex [**code 2**]	**2.4** Marital status ***(****if age above 18*) ***[*****code 3*****]***	***2.5*** Religious affiliation [**code 4**]	**2.6** Occupation **[See code 5]**		***2.7*** Highest level of education (completed) [for education level different from 1- 12 ***[*****code 6*****]***	***2.8*** Length of years in the current residence [write *years]*	***2.9*** Responsibility in the community ***[*****code 7*****]***
					Main	Secondary			

Codes for 1:1= Head 2= Wife/Husband/Partner3= Son/daughter 4= Grandchild 5= Father/Mother 6= Sister/Brother 7= Niece/nephew 8= Uncle/Aunt 9=Son/Daughter-in-law 10= Father/Mother-in-law 11= Brother/Sister-in-law 12= Grandparent 13= Other relative of head or of his/her spouses 14=Servant (farm worker, herder, maid) 15= other (specify) _____________

Codes for2: 1=Male 2=Female

Codes for 3: 1=Married, single spouse; 2= Married with more than one spouse/ polygamous; 3=Single; 4=Divorced; 5=Widowed; 6= Separated

Codes for 4: 1=Orthodox; 2=Muslim; 3=Catholic; 4=Protestant, 5=Indigenous religions; 6= other (specify) _____________

Cods for 5*:* 1=None, 2=Farmer; 3=Farm assistant, 4= Salaried work; 5=Student; 6= Farming/crop production and sales; 7= Livestock production and sales; 8=Non-farm product trader; 9=Beverage (*tella*, *tej*, *areke*, etc), 10= Wage labor (local); 11=Pensioner; 12=Handicraft, 13=Mining, 14=Carpentry, 15=House help, 16= Sale of wild/bush products (including charcoal;17=blacksmith 18=looking for work 19=other (specify) _____________

Codes for 6: 0=Can not read and write; 13=10+1; 14=10+2; 15=10+3; 16=Certificate; 17=Diploma; 18=Degree; 19=Masters and above; 20=non-formal education (can read and write); 21=KG (Completed)

Codes for 7: 1= None; 2**=**Religious leader; 3= Coordinator of community development work; 4=*Kebele* Administrator; 5= other (specify) _____________

2.10 Is this your village of origin? 1=Yes 2=No

2.11 If your place of birth is different from the current place, what is the reason for coming here? (**Multiple response is possible)**

1=Marriage; 2=Join relative; 3=Displacement by drought; 4=Displacement by flooding; 5=Divorce 6=Search for agricultural land; 7=War/conflict; 8=others specify____________________

2.12 Ethnicity of the household head: 1=Wolaita; 2 Gamo; 3=Dawro; 4=Sidama; 5=Amhara 6=Oromo 7=Tigray; 8=other (specify) _____________

2.13 Number of permanent household members: Male_________female_____________

2.14 Capable to work 1=Yes; 2=No

2.15 If agriculture is your major livelihood activity, for how long did you work on agriculture? (write in years) ________________________

2.16 Which farming system are you following currently? 1=Only crop production; 2= Livestock raring; 3=Mixed farming (Crop production and livestock raring)

2.17 Have you changed your farming system in the past 5-10 years? 1=Yes 2=No

2.18 If yes for QN # 2.17, why did you change the farming system you were following? (**Multiple response is possible)**

1=Decrease in rainfall amount; 2= Drought; 3=Decrease in productivity of livestock; 4=Decrease in productivity of land; 5=Decrease in grazing land; 6=Increase in pest and disease; 7=Others specify_________________

MODULE 3: HOUSEHOLD SOURCES OF INCOME (ON-FARM, OFF-FARM AND NON- FARM ACTIVITIES)

3.1 What are the sources of livelihoods and estimated earnings for all members in the household? (Answer all that apply)?

Farming activities	**Codes (**1=Yes;2=No**)**	Estimated monthly income	Estimated yearly income
Crop production			
Livestock rearing			
Fruit production (Apple, mango, Banana)			
Beekeeping			
Off-farm activities			
Non-farm activities			
Other activities (specify)			

3.2 Do any of your household members work in activities apart from crop production? 1=Yes; 2=No

3.3 If yes for QN #3.2, what are the types of **off-farm** livelihood activities that you are engaged in the last 12 months?

No.	**Type of off-farm activities**	**Participation code (**1=Yes;2=No**)**	**Number of months engaged in off-farm activities**	**Estimated annual income earned in *Birr***
1.	Sale of agricultural labor			
2.	Sharecropping (cash or food)			
3.	Livestock herding			
4.	Sale of firewood or charcoal			
5.	Sale of grass or fodder			
6.	Sale of wood			
7.	Petty trading (salt, soap, sugar)			
8.	Migratory labor (for a week or more)			
9.	Remittances			
10.	Gifts/inheritance			

3.4 If yes for QN #3.2, in which of the **non-farm** activities that you are engaged in the last 12 months?

No.	**Type of non-farm activities**	**Participation code** (1=Yes;2=No)	**Number of months engaged in non-farm activities**	**Estimated annual income earned in *Birr***
1.	Trading grains and pulses			
2.	Trading livestock			
3.	Drinks production and sales			
4.	Weaving /spinning			
5.	Carpentry			
6.	Pottery			
7.	Blacksmithing or			

	metalwork			
8.	Traditional healers	`		
9.	Renting out pack animals			
10.	Others (specify)			

3.5 For what purpose, did you use the income obtained from non-farm/off-farm activities? (Multiple response is possible) 1=Buy food; 2=Saving; 3=Buy clothes; 4=Pay taxes; 5=Pay loan; 6=Buy agricultural inputs; 7=others specify____________________

3.6 If you think that there is a challenge to engage in non-farm activities, what do you think are the possible reasons? (Multiple response is possible) [**use tick√ mark in front of the selection**]

1. Lack of spare time from agriculture		2. No employment opportunities	
3. Lack of awareness about its use		4. Jobs are too far away	
5. Lack of work skills		6. Poverty/lack of funds	
7. Unable to work due to old age		8. Income is intermittent	
9. Health problem		10. Others specify	

3.7 Is anyone from the family member work outside the community? 1= Yes; 2=No

3.8 If yes for QN # 3.7, how many in number? Males___________Females_________

MODULE 4: HOUSEHOLD EXPENDITURE AND CONSUMPTION INDICATORS

4.1 We would like to ask you about all the food that was bought for consumption or was consumed from your own (beteseb's) stock, IN THE LAST WEEK.

In last week, did your household consume any of the following? (FOOD-ITEM EXPENDITURE**)**

Food type	1. How much was purchased? How much was spent?			2. Did you consume this food from your own harvest or your own stock? How much?		3. Did you receive this food as a GIFT, a LOAN, as WAGE IN-KIND or as BARTER? How much? Who gave you this food? GIVE AMOUNT CONSUMED IN THE LAST WEEK		
	Response 1=Yes 2=No	**Amount (code 1)**	**Total expenditure**	**Response 1=Yes 2=No**	**Amount (code 1)**	**Response 1=Yes 2=No**	**Amount (code1)**	**Source (code 2)**
Teff								
Barley (Gebis)								
Wheat(Sinde)								
Maize (Bekolo)								
Sorghum (Mashila)								
Lentils (Misir)								

Horse Beans (Bakela)								
Cow Peas (Ater)								
Chick Peas(Shimbra)								
Milk/yoghourt (ergo)								
Mutton (yebeg)/goat meat (yefiyel siga)								
Chicken								
Eggs								
Butter/cheese								
Tella/Tej								
Birra (Bottled)								
Araqi/Kathikala								
Potatoes								
Sweet Potatoes								
Green leaf vegetables								
Enset								
Others (code 3)								

Codes for 1: 1=Kilograms; 2=Quintal; 3=Chinet; 4=Dawula; 5=Kuna; 6=Silicha; 7=Esir; 8=Litter; 9=Killo; 10= Gan;11=Ensira;12=Tassa; 13=Big Madaberia; 14=Small Madaberia; 15=Shekim 16=Others specify_____________

Codes for 2: 1=Family, local; 2=Family, non-local; 3=Neighbour/village member; 4= Individual from outside village; 5= Gift from government; 6= Gift from aid agency, NGO; 7= Food-for-work (PSNP); 8=Wages in kind; 9=Barter; 10=Loan; 11=Other specify ______________

Codes for 3: 1=Salt; 2 =sugar 3= cooking oil, 4= Spices/Karia/Berbere, 5= Bread (Dabo), 6= Macaroni/Spaghetti, 7= Honey 8= coffee 9=soft drinks and others specify_____________

4.2 Has the household purchased any prepared foods, or paid to eat food outside the household in the last week? (1 =Yes 2=No (If no, skip to QN#4.4.)

4.3 What was the total expenditure on prepared foods and food eaten outside the household in the last week? _________Birr)

NON-FOOD ITEM EXPENDITURE AND HOUSEHOLD CONSUMABLES: PART I

4.4 Did the household purchase any of the following for its own consumption during the last MONTH? If so, where did you purchase these?

Commodity	**Total expenditure (Birr)**	**The place purchased (code 1)**
1. Matches/Batteries		

2. Candles (tua'af), incense		
3. Laundry soap/OMO/endod/besana leaves, Hand soap		
4. Other personal care goods (incl. sendel, matent,)		
5. Charcoal/ Firewood		

Codes for 1: 1=This village, 2=Another village, 3=Local market town/Sodo, 4=Regional center/Hawassa, 5=Addis Ababa 6=Other (Specify)

NON-FOOD ITEM EXPENDITURE: PART II

4.5 IN THE LAST FOUR MONTHS, has the household purchased any of the following non-food items?

Commodity	**Total expenditure in the last four**	**Where purchased? (code 1)**
1. Clothes/shoes/fabric for men, women, goys, and girls		
2. Kitchen equipment (cooking pots, etc.)		
3. Linens (sheets, towels, blankets)		
4. Furniture		
5. Building materials		
6. Transport		
7. Ceremonial expenses (weeding, holiday)		
8. Contributions to *Iddir*		
9. Donations to the church		
10. Compensation and penalty		
11. Voluntary contributions		
12. Involuntary contribution (forced)		
13. Other goods purchased (code 2)		

Codes for 1: 1=This village; 2=Another village; 3=Local market town/Sodo; 4=Regional center/Hawassa; 5=Addis Ababa; 6=Other (Specify)____________

Codes for 2: 1= Savings and credit scheme; 2= Repair and maintenance; 3=Cosmetics (Hair oil, butter, perfume); 4= Bicycle or motor bicycle; 5=Bio-Gas tube (Oxygen gas); 6= Labor cost/salary; 7=Jeba, Gembo, Mitad, Broom and other such items; 8=Payment to broker

NON-FOOD ITEM EXPENDITURE: PART III

4.6 IN THE LAST FOUR MONTHS, has the household purchased any of the following non-food items?

Commodity	**Total expenditure in the last four**	**Where purchased? (code 1)**
1. Modern medical treatment and medicines		
2. Traditional medicine and healers		
3. School fees		
4. Other educational expenses (exercise books, pens, pencils, uniforms,		

maintenance, club fees)		
5. Cigarettes, tobacco, suret, gaya		
6. Alcoholic beverages		
7. Others specify		

Code 1: 1=This village, 2=Another village, 3=Local market town/Sodo, 4=Regional center/Hawassa, 5=Addis Ababa 6=Other (Specify)

MODULE 5: FOOD SECURITY INDICATORS

5.1 Indicate the months of not enough food, enough food and surplus food you have experienced during the last 12 months?

<table>
<tr><td colspan="12">0=Not enough food/food insecure
1= Just enough food/food sufficient
2= Plenty of food/surplus or food secure</td></tr>
<tr><td colspan="12">2008/2016</td></tr>
<tr><td>Jan</td><td>Feb</td><td>Mar</td><td>Apr</td><td>May</td><td>June</td><td>July</td><td>Aug</td><td>Sept</td><td>Oct</td><td>Nov</td><td>Dec</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="11">Total # of food needs met (all months with the score of 1 or 2)</td><td></td></tr>
<tr><td colspan="11">Total # of food gaps (all months with the score of 0)</td><td></td></tr>
</table>

5.2 Does the income you earn from non-farm or off-farm activities enable you to buy food for bridging the deficiency? 1=Yes 2=No

5.3 Did you or your household members face any food shortage in the last 12 months? 1= Yes; 2=No

5.4 If your household has faced food shortage over the last 12 months, what is the possible cause for this? **(multiple response is possible)**

1=Heavy rains/hailstorm; 2=Drought; 3=Diseases and pests; 4=Depleted soil nutrients; 5=Small land holdings; 6=Lack of enough money; 7=Traditional farming tools/system; 8=Big family size; 9=Other (Specify) ________

5.5 How did your household cope up during food shortage months? **(multiple response is possible)**

1=Purchase of grain from market; 2=Food aid; 3=Food/Cash from work; 4=Support from friends; 5=Credit cash; 6=income from off-farm; 7=Income from non-farm; 8 =Sale animals and animal products; 9=Others (specify) ____________________

5.6 How much quintal is the actual annual grain requirement of your household? (Estimate) __________________ Quintals

Food Access: Household dietary diversity score (HDDS) (Applicable to all households)

<table>
<tr><td>No.</td><td>HDDS QUESTIONS</td><td rowspan="2">Responsecodes</td><td rowspan="2">If yesterday was special or unusual day, skip this table</td></tr>
<tr><td colspan="2" rowspan="2">Now I would like to ask you about the types of foods that you or anyone else in your household ate yesterday during the day and at night. This does not include food that you ate at a restaurant or outside of the home.
Read the list of foods. Choose “yes” if anyone in the household ate the food in question. Choose “no” if no one in the household ate the food.
THE FOODS LISTED SHOULD BE THOSE PREPARED IN THE HOUSEHOLD AND EATEN IN THE HOUSEHOLD OR TAKEN ELSEWHERE TO EAT. DO NOT INCLUDE</td></tr>
<tr><td></td><td></td></tr>
</table>

FOODS CONSUMED OUTSIDE THE HOME THAT WERE PREPARED ELSEWHERE.			
1.	Any enjera, bread, rice, biscuits, or other foods made from teff, millet, sorghum, maize, rice, pasta, macaroni, wheat or barley or other cereal.	1 = Yes, 2 = No	
2.	Any potatoes, yams, cassava, or any other foods made from roots or tubers?	1 = Yes, 2 = No	
3.	Any vegetables?	1 = Yes, 2 = No	
4.	Any fruits?	1 = Yes, 2 = No	
5.	Any meet, beef, lamb, goat, wild game, chicken, liver, kidney, heart, or other organ meats?	1 = Yes, 2 = No	
6.	Any eggs?	1 = Yes, 2 = No	
7.	Any fresh or dried fish?	1 = Yes, 2 = No	
8.	Any foods made from beans, peas, lentils, haricot beans, or nuts?	1 = Yes, 2 = No	
9.	Any cheese, yogurt, milk, or other milk products?	1 = Yes, 2 = No	
10.	Any foods made with oil, fat, or butter?	1 = Yes, 2 = No	
Sum of categories above (a scale of 0-10)			
11.	Any sugar or honey?	1 = Yes, 2 = No	
12.	Any other foods, such as condiments, coffee or tea?	1= Yes, 2 = No	

6 Did you participate in safety net programs in the past?1= Yes; 2=No

7 Currently, are you a member of productive safety net programs? 1= Yes; 2=No

MODULE 6: LIVELIHOOD VULNERABILITY AND RESILIENCE CAPACITY INDICATORS

1) Natural capital [Land, irrigated area and access to publicly owned resources]

6.1 Do you have access to land for agricultural use? 1=Yes; 2= No

6.2 If yes for QN #6.1, how did you get it?

1=through land redistribution 2=Shared with the family/relatives 3=Inherited from parents 4=Rented 6=Other (specify) ________________________

6.3 Do you have land use right/ownership certificate? 1= Yes 2=No

6.4 What are the total sizes of the following land types that you use?

Land type	**Unit in local measure (kada/timad or others)**	**In hectare**
Cultivated land		
Fallow land		
Grass and woodland		
Forest land/wood lot		
Homestead/backyard		

Irrigated land out of cultivated		
Total landholding		

6.5 What type of soil is your cultivated land? 1=Black 2=Brown 3=Red; 4= Other (specify) ___________

6.6 How did you plough your land? 1=Using pair of oxen/horses; 2=Using hand hoe; 3=Using machine or tractor; 4=Others specify______________________________

6.7 List the total area of land operated in 2008/2009 EC production season?

Land type	**Area in hectare (ha)**	**Fertility of soil [see code 1]**	**Status of farming land [see code 2]**	**Slope of the land [see code 3]**
Own land				
Rented inland				
Rented outland				
Share crop in				
Share crop out				
Fallow land				

Codes for 1: 1=Not fertile; 2= Somewhat fertile 3=Fertile; 4=Highly fertile
Codes for 2: 1=Increased; 2=remain the same/no change; 3=decreased; 4=Do not know
Codes for 3: 1=Flat; 2=Somewhat hilly;3=Highly steep;4=Mountainous;5=Other specify_____________

6.8 Have you sharecropped out your plot to other farmers on equal basis? 1=Yes 2=No

6.9 If yes for QN # 6.8, why did you sharecrop out**? (Multiple response is possible):**
1=Lack of draft power; 2=Lack of seed; 3=Unable to purchase technological inputs; 4=Elderly and unable to operate it; 5=Illness; 6=Having extra land; 7=Others, specify ________

6.10 Indicate your access to other publicly owned land resources

Indicator questions	**Code definition**	**Response**
1. Do you have access to open or publicly owned grazing land?	1=Yes 2= No	
2. Do you have access to open or publicly owned water source for livestock?	1=Yes 2= No	
3. Do you have access to get firewood from open or publicly ownedforested land?	1=Yes 2= No	

6.11 What benefit do you get from the open or publicly owned land? **(multiple response is possible)**
1=Grazing livestock; 2=Collecting fire wood; 3= Fire wood for selling; 4=Source of construction materials; 5=Other (specify) ______________________

6.12 What are the main constraints to your farmlands? **(multiple response is possible)**
1= Erosion; 2= Waterlogging; 3= Poor soil fertility; 4=Susceptibility to frost; 5= High concentration of stones on the topsoil; 6= Salinity; 7= Highly sandy; 8=Water scarcity-inaccessibility to water or drought; 9=Other (specify) ______________________

6.13 Did farm land related challenges force you to enhance the use of soil and water conservation management techniques (terracing, agroforestry, etc.)? 1=Yes 2=No

6.14 If yes for QN # 6.13, what is the size of your land area covered with improved soil and water conservation practices in hectare? _____________

6.15 Which measure(s) do you practice to minimize soil erosion on your own farm, and in your community at large? **(Multiple response is possible)**

1= Terracing; 2= Crop rotation; 3= Using compost; 4= Tree planting; 5= Soil or stone bunds; 6=Contour ploughing; 7=Furrowing; 8= Strip cultivation; 9= Other (specify) _____________________

6.16 Which of the following land management practice do you carry out in order to maintain and replenish the soil fertility of your farmlands? (**Multiple response is possible)**

1= Fallowing (field rotation); 2= Crop rotation; 3= Manuring; 4= Use of fertilizers (e.g., Dap, Urea, and blended fertilizer); 5= Inter-cropping; 6= Other (specify) _____________________

6.17 How do you see the status of your land size over the last 5-10 years?

1= Highly increased; 2= Increased; 3= No change; 4= Decreased; 5= Highly decreased

6.18 If your answer is decreasing for QN # 6.17, what is the possible reason for the decrease for farm land size? **(Multiple response is possible)**

1=increased demand for agricultural land; 2=land degradation; 3=land fragmentation; 4=conversation of farm land to non-farm activities; 5=limited carrying capacity or population pressure; 6=others specify________

2) Crop Production

6.19 Would please indicate the type of crops/vegetables you have produced/, land area covered by crops, amount sold, and income earned from sales of crops during the year 2008/2009 E.C

Crop types	Have you produced […]? 1=Yes; 2=No	Area covered (Timad) (Kada)	Production (qt) (quintal/hectare)	Amount sold (quintals)	Income from sales (Birr)
Maize					
Teff					
Wheat					
Barley					
Haricot bean					
Sorghum					
Lentil					
Coffee					
Tomato					
Potato					
Cassava					
Taro					
Onion					
Enset					
Carrot					
Beet root					
Other specify					

6.20 What are criteria used to select crops for production? (Multiple response is possible)

1=Drought tolerance; 2=Pest and disease tolerance; 3=The time it takes to mature; 4= High market value; 5=High yield crop/productivity; 6=others, specify __________

6.21 Would you list the type and amount of agricultural inputs you used in the 2008/2009 cropping year?

Type of agricultural inputs		**Responses 1=Yes 2=No**	**Total amount used in Kg.**	**Total amount of costs incurred**	**Total area covered using inputs (in Ha)**
Chemical fertilizers	DAP				
	Urea				
	Blended fertilizer				
Pesticides/herbicides					
Improved seeds					
Others specify					

6.22 If there are constraints on the use of agricultural inputs, what are the problems? **(Multiple response is possible)** 1=Drought/erratic rainfall; 2=High price of inputs; 3=Lack of cash; 4=Indebtedness; 5 =Farm land is inappropriate to use of fertilizers; 6=Crop disease; Excessive rain/flooding; 7=Unavailability of improved seed; 8=Untimely input distribution; 9= Other, please specify_______________________

6.23 In general, what is the trend of your crop production for the following crop types over the last 5-10 years?

Crops produced	**Trends in crop production**				
	Highly decreased	**Decreased (2)**	**No change (3)**	**Increased (4)**	**Highly increased**
1. Maize					
2. Wheat					
3. Barely					
4. Teff					
5. Sorghum/					
6. Peanuts					
7. Chickpea (shinbira)					
8. Bean (baqella)					
9. Pea (atar)					
10. Enset					
11. Taro					
12. Sweet potatoes					

6.24 What are the possible reasons for any increase in your cultivated land productivity? **(Multiple response is possible)**

1=Increased soil fertility; 2=Improved seed supply; 3= Improved agrochemical use; 4= Improved use of organic fertilizer; 5=Suitable weather conditions/good rainfall; 6=Soil and water conservation practices; 7= Other, please specify______________________

6.25 What are the possible reasons for any decrease of your cultivated land productivity? **(Multiple response is possible)**

1=Land degradation; 2=Lack of timely input supply; 3= Lack of oxen; 4=Erratic rainfall /variability;5=Drought; 6= Land scarcity; 7= Non-use of fertilizer; 8=Pests and crop diseases; 9= Other, please specify______________________

3) Livestock Ownership/Production

6.26 Please indicate the number of livestock owned by the household and the estimated current value per each

Type	**Number of livestock ownership status**		**Equivalence in cash currently (in *birr*)**
	Last year	This year	
1. Cows			
2. Oxen			
3. Bulls			
4. Heifers			
5. Calves			
6. Sheep			
7. Goats			
8. Mules			
9. Horses			
10. Donkeys			
11. Chicken			
12. Bee colony			

6.27 How do you perceive the current livestock production compared to 5-10 years ago?
1= Highly increased; 2= Increased; 3= No change; 4= Decreased; 5= Highly decreased

6.28 If decreased for QN #6.27, what would be the cause? **(Multiple response is possible)**

1=Livestock disease prevalence; 2=Shortage of grazing land; 3=Natural disaster (e.g. drought); 4=Scarcity of fodder; 5=Shortage of hybrid; 6= Lack of sufficient veterinary services; 7= Shortage of water; 8= others (specify) ___________________________

4) Household Assets Ownership

6.29 **Could you please tell us the number of** productive assets **you own currently, number of each asset and the cash equivalence of each asset in Birr?**

Type of assets	**Response 1=Yes; 2=No**	**If yes for each, number of asset owned**	**Cash equivalence of the asset**
1. Axe (Metarabia)			

2. Machete			
3. Sickle (machid)			
4. Spade (Akafa)			
5. Hoe(doma)			
6. Bucket			
7. Grain mill(weficho)			
8. Plough(maresha)			
9. Plow/Yoke/ Kenber			
10. Plow/ Beam/			
11. Plow/Share			
12. Horse/Mule/Ox Cart			
13. Modern bee hive			
14. Traditional bee hive			
15. Weaving equipment			
16. Gotera or Dibignit			Not applicable
17. Hammer (fas or martelo)			
18. Saw(megaz)			

6.30 **Could you please tell us the number of** household assets **you own currently, number of each asset and the cash equivalence of each asset in Birr?**

Type of assets	**Response 1=Yes 2=No**	**If yes, number of assets owned**	**Cash equivalence in Birr**
1. Blankets/buluko/gabis			
2. Bed (alga)			
3. Chairs			
4. Tables			
5. Cupboard (Sanduk/Kumsatin)			
6. Leather Mat (Kurbet, Agoza, Debdab)			
7. Flashlight (torch)			
8. Watch/clocks			
9. Kerosene stove			
10. Radio/cassette player			
11. DVD player			
12. Television			
13. Mobile phone			
14. Bicycle			
15. Motor bicycle			
16. Iron (Kawuya)			
17. Leather Pouch (Silicha)			
18. Mechegia (Leather Sofa)			
19. Jewelry/Gold/Maria Theresa Coin, Ring			
20. Guns(Tebmenja)			
21. Spear/Sword (Gorade)			
22. Shield (Gasha)			

6.31 Has any household member lost any of the above mentioned productive assets due to the last year (2007/2008) drought? 1= Yes 2= No

6.32 If yes for QN # 6.31, what are the major impacts of the drought on your productivity that your household has experienced during the last 12 months? **(Multiple response is possible)**

1= Loss of productive assets; 2= Loss of household income; 3=Reduction in household consumption; 4= Asset and income loss; 5= Asset loss and reduced consumption; 6= Income loss and reduced consumption; 7= Other specify___

5) Access to Financial Capital

6.33 Did you have access to any cash credit service from any source during the last 12 months?

1= Yes 2= No

6.34 If yes for QN# 6.33, please indicate your access to credit services, amount and purposes of loan?

No.	Source of credit	Amount of credit received in *Birr*	For what purpose did you receive the money? (use code 1)
1.	Marketing cooperative		
2.	Local money lender		
3.	Friends/relatives		
4.	NGOs		
5.	Omo MFIs		
6.	Banks		
7.	Vision fund		
8.	Religious institutions		
9.	Saving group		
10.	Women group		
11.	Iddir		
12.	Equib		
13.	Others, specify		

Codes for 1: 1= Petty trade; 2 = Food grain purchase; 3 = Input purchase for crop production; 4 = Animal purchase; 5 = Other income generating activities; 6 = Repay debt; 7= others, specify ______________

6.35 If no for QN # 6.33, what was the problem? **(multiple response is possible)**
1= Did not want to take loan; 2=couldn't find a loan that met my needs; 3=Afraid I couldn't pay back; 4= No loan providers in the locality; 5= others, specify ______________

6.36 Do any of the household members have cash saving? 1=Yes 2=No

6.37 If yes for QN # 6.36, where is the saving held?
1= Credit or micro-finance institution; 2=Banks; 3=Religious institutions; 4=Saving group; 5=Vision fund; 6=Women's group; 7=Others specify__________________

6.38 What is the total amount of saving in *Birr*? ___________________________

6.39 What is the primary purpose of saving? **(multiple response is possible)**
1=To use in time of emergencies; 2=To buy livestock; 3=To buy agricultural inputs; 4=To pay debts; 5=Others specify_________________

6.40 Do any of the household members have existing debt from any one? 1=Yes 2=No

6.41 If yes for QN # 6.40, what is the total amount of credit to be paid? ___________________

6) Network/Relationship (Social Capital)

No.	Indicator questions	Response

1.	In the past months in a year, did relatives or friends help you and your family (e.g., to get medical care or medicines, sell animal products or other goods produced by the household, take care of children, worked in field?	1=Yes 2= No
2.	In the past months in a year, did you and your family help relatives or friends?	1=Yes 2= No
3.	Has anyone from your family participate in informal association (*Iddir, equib, mahaber et*c)	1=Yes 2= No
4.	If yes for QN # 3, are there bylaws to govern the groups?	1=Yes 2= No
5.	Has anyone from your family participate in informal association (*debo or* working groups)?	1=Yes 2= No
6.	If yes for QN # 4, what is the number of non-working days/month in the debo? ________________days	
7.	How do you rate the culture of working together in your community? 1=Very weak, 2=Weak, 3=Fair, 4=strong, 5=Very strong	
8.	Has anyone of your family member involve in formal association? (local leadership, dev't group, one-five organization, & others?	1=Yes 2= No
9.	Has anyone of your family member involved in cooperative?	1=Yes 2= No
10.	Has anyone of your family member involved in household asset building program/HABP?	1=Yes 2= No
11.	Has anyone of your family member involved in disaster reduction and early warring/DRR-EW committee?	1=Yes 2= No
12.	Has anyone of your family member involved in hazard insurance schemes?	1=Yes 2= No
13.	Has anyone of your family member involved in shock preparedness and mitigation program or schemes?	1=Yes 2= No
14.	Has anyone of your family member involved in vision fund (VF)?	1=Yes 2= No
15.	Has anyone of your family member involved in women group?	1=Yes 2= No
16.	Has anyone of your family member involved in religious group?	1=Yes 2= No
17.	Has anyone of your family member involved in charitable group?	1=Yes 2= No

7) Health, Trainings /Skills

No.	Indicator questions	Response code
1.	Is anybody in your family chronically ill?	1=Yes 2= No
2.	Has anyone in your family been so sick in the past 1 month that they had to miss work or school?	1=Yes 2= No
3.	Has anyone in your family been suffered by TB, Malaria, Cholera or other communicable diseases in the past six months?	1=Yes 2= No
4.	Has anyone in your household has died due to illness or natural disasters (drought, floods, landslides, malnutrition) in the past 5-10years?	1=Yes 2= No
5.	Has anyone in your household has been injured due to the climate-related disasters (drought, flood, epidemics etc…) in the past 5-10years?	1=Yes 2= No
6.	Do you have access to health extension services in your locality?	1=Yes 2= No

7.	If yes for QN # 6, 1=Daily 2=Weekly 3=Fortnightly 4=Monthly 5=Biannually 6=Annually	
8.	Do you send your children to school?	1=Yes 2= No
9.	Have you received any training over the last 12 months?	1=Yes 2= No
10.	If your answer is yes for QN # 9, could you state the number of trainings you have attended over the last 12 ______________months?	
11.	Type of trainings attended (multiple response is possible) 1= Crop Management/Production; 2= Livestock Production (animal health/fattening); 3= Financial Literacy; 4= Health/Family Planning; 5= Climate change adaptation/conservation; 6= Business skills (income generating activities); 7= Value Addition (Marketing); 8= Nutrition (dietary diversity); 9= Poultry Production; 10= Early warning and disaster risk management; 11=Others specify_____________________________	
12.	Do you have additional skills?	1=Yes 2= No
13.	If yes for QN # 11, what are these skills?	
1=Carpentry; 2=Weaving; 3=Handcrafting; 4=Tannery; 5=Pottery; 6=Metalwork; 7=Traditional medicine 8=Others specify____________		

MODULE 7: ADDITIONAL RESILIENCE CAPACITY INDICATORS

1) Physical capital

No.	Indicator questions	Response code
1.	Do you or your family own a house?	1=Yes 2= No
2.	What is the construction materials used for outside walls and roof of your house? 1= Mud/dung (chika/ebet); 2=Wood; 3=Galvanised iron (korkoro); 4= Stone/Brick/Concrete/Cement; 5= Thatch (sar) 6=Bamboo 7=others specify	
3.	Do you have access to clean and safe [drinking] water supply?	1=Yes 2= No
4.	What is the main drinking water for your household? 1=Piped in 2=Tube well/borehole with pump 3=Protected dug well 4=Open/unprotected well-5=Protected spring 6=River/stream	
5.	Who normally collect water for the household? 1=Men 2=Women 3=Both	
6.	Do you use a toilet [does not include outdoors defecation]?	1=Yes 2= No
7.	What is the main source of lighting for the house? 1=Bottle lamp 2=Kerosene 3=Candle 4=Wood fire 5=Other (specify)	
8.	What is the main source of cooking fuel for the household? 1=Wood 2=Charcoal 3=Gas 4= Kerosene 5=Dung 6=Crop residue 7=Other (specify)	
9.	If you collect wood for QN #8, how long does it takes to go there and comeback? _________ min/hours	
10.	Who normally collect firewood for the family? 1=Men 2=Women 3=Both	

2) Access to Infrastructure

No.	Indicator questions	Walking distance	Walking distance(one

		(one way) in KM	way) in minutes
1.	How far is your home from all weather-roads?		
2.	How far is your home from healthcare center?		
3.	How far is your home from the savings and credit institutions?		
4.	How far is your home from the village market/within the *Kebele*?		
5.	How far is your home from the main market (central for *Wereda*)		
6.	How far is your home from the primary school?		
7.	How far is your home from the secondary school?		
8.	How far is your home from the farmers training center?		
9.	How far is your home from the veterinary services?		
10.	How far is your house from the safe drinking water?		

3) Access to Information and Services

No.	Indicator questions	Response code
1.	Do you have access to climate-related information?	1=Yes 2= No
2.	Do you have access to early warning information system?	1=Yes 2= No
3.	If yes for QN # 2, what type of early warning information providing structure are put in place?	1=Formal/government; 2=Informal/traditional
4.	If yes for QN # 2, how often have you been informed about the potential risk of natural disasters (erratic rainfall, flooding, land slid, outbreak of crop pests and diseases)	1=Frequently; 2=Occasionally/seasonally; 3=Rarely
5.	Who provides the information on early warning?	1=Government; 2=NGOs; 3=CBOs; 4=All of them
6.	How do you rate the contribution of the early warning system for you to withstand from the shocks?	3=High; 2=Medium; 1=Low; 0=None
7.	Do you have access to agricultural extension services?	1= Yes 2= No
8.	Does the presence of extension services help you to improve productivity and production?	1= Yes 2= No
9.	How often do you meet and get advice from the extension agent? 1=Daily; 2=Weekly; 3=Once in two weeks;4=Monthly; 5=Once in three months 6=None/not at all	
10.	How often the extension agent visits you to provide extension information? 1=Daily; 2=Weekly; 3=Once in two weeks;4=Monthly; 5=Once in three months 6=None/not at all	
11.	How often you go to the extension agent seeking agricultural information? 1=Daily; 2=Weekly; 3=Once in two weeks;4=Monthly; 5=Once in three months 6=None/not at all	
12.	Do you get important information related to agriculture and market from this information? center/source?	1= Yes 2= No
13.	Do you have access to irrigation sources (pond, diversion canal, etc.)	1= Yes 2= No
14.	Do you have access to security services that can reach the	1= Yes 2= No

	community within 1 hour?	
15.	Do you have access to micro-insurance scheme or program in your locality?	1= Yes 2= No
16.	If yes for QN # 13, what type of micro-insurance program are you involved in?	1=Crop 2=Livestock 3=Both 4=Others specify_______________

4) Availability of Formal and Informal Support Mechanisms

No.	Indicator questions	Response code
1.	Is there any institution in your locality where people can receive food assistance in time of shock or emergences?	1= Yes 2= No
2.	Is there any institution in your locality where people can receive non-food assistance in time of shock or emergences?	1= Yes 2= No
3.	Is there any institution in your locality where people can receive assistance due to losses of livestock?	1= Yes 2= No
4.	Is there any institution working on disaster response program from government or NGOs?	1= Yes 2= No

MODULE 8: FARMERS' PERCEPTION TO CLIMATE VARIABILITY OR CHANGE

8.1 To what extent would you agree or disagree that the options indicated in the table below apply as possible reasons to responses by your household to the climate trend (Changes of temperature and precipitation)

No.	Perception indicators	Level of agreement or disagreement (five-point scale)				
Change in temperature		Strongly agree (5)	Agree (4)	Neutral (3)	Disagree (2)	Strongly disagree (1)
1	Temperature has increased					
2	No change in temperature					
3	Temperature has decreased					
4	Rainy season temperature has decreased					
5	Dry season temperature has increased					
6	Number of hot days in a year increased					
Change in Amount rainfall						
1	Rainfall has increased					
2	No change in rainfall					
3	Rainfall has decreased					
4	Rainfall starts lately					
5	Early cessation of rainfall					
6	Belg rain has decreased					
7	Rain fall during main rainy season has decreased					

MODULE 9: CLIMATE INDUCED SHOCKS INDICATORS

9.1 Have you ever faced crop failure during the last 10-20 years?

1=Yes 2=No

9.2 If yes for QN# 9.1, what are the main reason for the crop failure? **[Multiple response is possible]**

1=Erratic rainfall; 2=Lack of Improved seeds; 3=Unaffordable price of inputs; 4=Low level of soil fertility; 5=Pest and disease; 6=Shortage of farm oxen; 7=Other (specify)________________

9.3 Have you ever experienced flooding due to excessive rainfall over the last 10-20 years?

1=Yes 2=No

9.4 If yes for QN# 9.3, how do you rate the frequency of flooding in your locality over the last 10-20 years?

5= Highly increased; 4= Increased; 3= No change; 2= Decreased; 1= Highly decreased

9.5 Have you ever experienced drought due to climate variability/change over the last 10-20 years?

1=Yes 2=No

9.6 If yes for QN # 9.5, how do you rate the frequency of drought in your locality over the last 10-20 years?

5= Highly increased; 4= Increased; 3= No change; 2= Decreased; 1= Highly decreased

9.7 Have you ever experienced disease (crop, livestock, and human) disease outbreak due to climate variability/change over the last 10-20 years?

1=Yes 2=No

9.8 If yes for QN# 9.7, how do you rate the frequency of disease outbreak in your locality over the last 10-20 years?

5= Highly increased; 4= Increased; 3= No change; 2= Decreased; 1= Highly decreased

1) Self-Reported Climate-Related Shock Indicators

9.9 Please indicate your experiences with climate-induced shocks, frequency of occurrences over the last 10-10 years and estimated costs of the damage due to the shocks

Experience of the following shocks	**Frequency of shocks over the last (10-20 years)**	**Severity 1=High, 2=Medium, 3=low**	**Estimated costs of the damage on property/livelihood/health in *Birr***
1. Flooding			
2. Drought			
3. Crop failure			
4. Crop pests and diseases			
5. Livestock disease			
6. Human disease/human health problem			
7. Food crisis			

9.10 Who has been affected most by the above-mentioned shocks?

1=Men; 2=Women; 3=Children; 4=Elders; 5=All segment of the society

2) Subjective Resilience Indicators

9.11 We would like to ask you about your level of agreement or disagreement if climate resulted shocks [**INSERT THE SHOCK TYPE**] were occurred/will be occurred, and your household would be/will be able to successfully deal with the threats posed in the past/to be posted in the future?

Type of shock anticipated [occurred in the past five years/last year]	Level of agreement on households' capacity to withstand from shock [NAME THE SHOCK] in the past and level of agreement for each shock [PAST CAPACITY] (**code 1**)	Level of agreement for the likely occurrence of shocks [NAME THE SHOCK] in the future (next year/five years) and household capacity to withstand from each shock [FUTURE CAPACITY] (**code 1**)
Flooding		
Drought		
Crop pests and diseases		
Livestock disease		
Human disease		

Codes for 1: 1= Strongly disagree, 2= Disagree 3= Neutral, 4= Agree, 5= Strongly agree

9.12 Which of the following statements best describes the extent to which you and your household have been able to recover from the last drought (2015/6/2007/8 E.C)?

1=Did not recover; 2=Recovered some, but worse off than before drought; 3=Recovered to same level as before drought; 4=Recovered and better off; 5=Not affected by drought

9.13 Which of the following statements best describes your household's ability to cope with and manage with future droughts or future periods of shocks or stress?

1=Unable to cope; 2=Able to cope, with changes income and food sources; 3=Able to cope without difficulty; 4=Others specify______________________________

MODULE 10: PERCEIVED CLIMATE IMPACTS OF CLIMATE CHANGE AND VARIABILITY

10.1 Would you please indicate the type of impacts that climate change has brought to you or your household?

No.	Indicators questions	Dummy	Response
1.	Crop productivity decline	1= Yes 2= No	
2.	Shortage of water for irrigation	1= Yes 2= No	
3.	Shortage of water for home/animal consumption	1= Yes 2= No	
4.	Emergence/resurgence of new pests (weeds) and	1= Yes 2= No	
5.	Increased level of temperature	1= Yes 2= No	
6.	Increased frequency of drought	1= Yes 2= No	
7.	Increased frequency of flooding	1= Yes 2= No	
8.	Geographic isolation/inaccessibility	1= Yes 2= No	
9.	Livestock disease	1= Yes 2= No	
10.	Crop pests and diseases	1= Yes 2= No	

11.	Local conflict over diminishing resources	1= Yes 2= No	
12.	Food price inflation	1= Yes 2= No	

Thank you for your cooperation!!

Annex 1.2Key Informant Interview Guide (community KIIs)

Part I: Background information

1. Name of respondent: ______________________________
2. Position of respondent: ____________________________
3. Education level__________________________________
4. Work experiences________________________________
5. Region____
6. Zone____
7. *Wereda* _______________________________________

Part II: Guiding questions

1. How do describe the trend of long-term changes in relation to the timing and intensity of rainfall in your locality?
2. What differences have you observed throughout your life?
3. How do describe the change in temperature over the last few decades?
4. What are the corresponding changes with the rainfall and temperature changes over the last few decades?
5. What do you think are the major reasons for those changes in temperatures and rainfall over the last few decades?
6. What were the adverse effects of those changes in relation to your livelihood and your community?

7. What were the effects of the changes in the status of your natural environment (soil, water and vegetation)?
8. What harms have you and your family experienced due to the changes in rainfall and temperatures?
9. How long and frequent have the harms been to you and your family?
10. What is a period of plenty, and what is a period of scarcity in your locality?
11. How long does each of these periods last in a year?
12. What characterizes these periods?
13. What measures have you been taking to overcome the harms and how successful were these measures in protecting you and your family from severe harms?
14. What assets/resources do you spare to be used during difficult times and how adequate were these assets/resources to overcome those difficulties?
15. Have you been receiving any help to withstand the shocks?
16. Who has been helping you? How adequate was the help to overcome the harms?
17. What do you think could be a lasting solution to protect you and your family from the harmful effects of the changing climate, who should do what?

Annex 1.3Key Informant Interview Guide (for government offices)

Part I: Background information

1. Name of respondent: ______________________________
2. Position of respondent: ____________________________
3. Education level__________________________________
4. Work experiences________________________________
5. Region____
6. Zone____
7. *Wereda* ____

1. How do you describe the status of climate variability and change in your *Wereda*?
2. What were the effects of the changing climate in your *Wereda* and how do you describe the trend?
3. What are the corresponding changes with the rainfall and temperature changes over the last few decades?

4. What do you think are the major reasons for those changes in temperatures and rainfall over the last few decades?
5. What were the adverse effects of those changes in relation to the livelihoods of farming households and their community?
6. What were the effects of the changes in the status of the natural environment (soil, water and vegetation)?
7. What were the climate-induced shocks and how severe were they?
8. What assets and resilience capacities do the community members have?
9. What is the extent of households' vulnerability to the shocks? Who is more vulnerable than others? And why?
10. What do the households do during shock periods? What assets are in their disposal? How adequate are these assets?
11. What are the mechanisms that the households are supported to withstand the shocks?
12. How adequate were the supports in building their capacity to withstand the shocks?
13. What do you think could bring about a lasting solution to build the resilience of farming households against the climate-induced shocks?

Annex 1.4Group discussion guide

Part I: Introduction /Warm-up:

1. Acknowledge participants for their willingness to take part in the FGD.
2. Explain the purpose of the group discussion.
3. Introduce yourself.
4. Explain the role of the facilitator and note takers.
5. Let participants introduce themselves (list their name, sex, and other, if apt).

Part II: Instruction:

1. Assure all participants personal data will be kept confidential and will not be used for unintended purpose. I.e., all the data provided will be used only for the study purpose.
2. Make clear what is expected of participants.
3. Make clear the time length of the discussion (between 45-60 minutes).
4. Keep eye contact with the participants and make sure that the discussion is participatory for everyone.
5. Set ground rules for the group with the participants: Consider the following rules:
   - Respect for different views, no wrong answers, one person speak at a time,

everyone has the right to speak without being interrupted, raise your hands and get a signal from the facilitator before your talk, keep your answers short and precise to allow others participate, switch off/silence your cellphones.

6. Do NOT promise what you cannot deliver.
7. Use a translator, whenever necessary.

Part III: Closing and post discussion activities:

1. Summarize the ideas which emerged from the focus group, noting where there was consensus and where there was no consensus) on the themes of discussion.
2. Let participants add anything before you close.
3. Thank everyone for their time and input in the discussion.
4. Make sure to write the group discussion report immediately after the discussion.

FGD discussion guide:

1. We will start by introducing ourselves. Please tell us your name, your age, *Kebele*, level of education, agro-ecology, and how many members in your family?
2. How do describe the trend of long-term changes in relation to rainfall and temperatures in your locality? What differences have you observed over the last few decades?
3. What are the corresponding changes with the rainfall and temperature changes over the last few decades?
4. What do you think are the major reasons for those changes in temperatures and rainfall over the last few decades?
5. What were the adverse effects of those changes in relation to your livelihood and your community?
6. What were the effects of the changes in the status of your natural environment (soil, water and vegetation)?
7. What harms have you and community experienced due to the changes in rainfall and temperatures?
8. How long and frequent have the harms been to you and your family?
9. What is a period of plenty, and what is a period of scarcity in your locality? How long does each of these periods last in a year?
10. What characterizes these periods?
11. What measures have you been taking to overcome the harms and how successful were these measures in protecting your family and community from severe harms?

12. What assets/resources do you spare to be used during difficult times and how adequate were these assets/resources to overcome those difficulties?
13. Have you been receiving any help to withstand the shocks?
14. Who has been helping you? How adequate was the help to overcome the harms?
15. What do you think could be a lasting solution to protect you and your community members from the harmful effects of the changing climate, who should do what?

Annex 1.5Direct observation checklist

Part 1. Background information of observation area

1. Name of *Kebele* of observation ________
2. Name of specific village of observation _____________
3. Number of households in the village ______

Part 2. Guidelines for observation: the following issues will be observed.

1. The condition of housing of the study communities or households;
2. The condition of infrastructure (health facilities, schools, farm training center, potable water, roads, saving and credit institutions so forth);
3. The condition of agricultural activities and farming system;
4. The level of resource dependence by communities;
5. Climate induced impacts of the study area;
6. The level of community networking and participation in public works;
7. The level of social support system and functionality the schemes in place;
8. The vulnerability situation of the study households.
9. The various resilience building packages put in place.

Annex 1.6. List of KIIs involved in the PhD study over AEZs

KII No.	Level	Position held
KII-1	Zone	World Vision, Wolaita Carbon Project Coordinator
KII-2		Disaster Risk Management Representative
KII-3		Agriculture Office Representative
KII-4	*Wereda*	*Wereda* Agriculture Office Head (Highland)
KII-5		*Wereda* Agriculture Office Head (Midland)

KII-6		*Wereda* Agriculture Office Head (Lowland)
KII-7	*Wereda*	Disaster Risk Management Officer (Highland)
KII-8		Disaster Risk Management Officer (Midland)
KII-9		Disaster Risk Management Officer (Lowland)
KII-10	*Wereda*	Food Security Head (Highland)
KII-11		Food Security Head (Midland)
KII-12		Food Security Head (Lowland)
KII-13	*Kebele*	*Kebele* Administrator (Highland)
KII-14		*Kebele* Administrator (Midland)
KII-15		*Kebele* Administrator (Lowland)

Annex 4.1 Major components and indicators

LVI-IPCC contributing factors	Livelihood capitals	Major component	Indicators
Exposure	Natural	Climate change and variability	Mean SD of Ave. monthly maximum temperature (ºC) (1983-2014) Mean SD of Ave. monthly minimum temperature (ºC) (1983-2014) Mean SD of Ave. monthly precipitation (mm) (1983-2014) % of HHs that did not perceive climate change over 20 years
		Natural disaster	% of HHs reporting droughtoccurrences over 20 years % of HHs reporting floods occurrences over 20 years % of HHs reporting injury of a family member due to climate hazard % of HHs reporting crop disease/pest outbreak over 20 years % of HHs reporting livestock disease outbreak over 20 years % of HHs who did not receive a warning about natural disaster
Sensitivity	Natural	Land use and sustainability	% of HHs with non-suitable cultivated land (not fertile land) % of HHs not practicing soil and water conservation % of HHs with micro-holders (0.-0.5 ha)
		Agriculture	Ave. no. of food gap months from own production Crop diversity score (inverse) Annual income (sales of crop, livestock, non-farm, and off-farm) (*Birr*) (inverse)
laptive capacity	Financial	Wealth	Livestock in total livestock unit (TLU) (inverse) Cultivated farm size (ha) (inverse) Estimated value of HH productive assets in (*Birr*)

LVI-IPCC contributing factors	Livelihood capitals	Major component	Indicators
			(inverse) % of HHs who do not have access to credit
	Physical	Technology	% of HHs not using farm chemicals % of HHs not using farm chemicals fertilizer % of HHs not using improved seed % ofHHs not practicing irrigation
		Infrastructure	Ave. time to reach human health facility (walking hours) Ave. time to reach to all weather-roads (walking hours) Ave. time to reach to school (walking hours) Ave. time to reach to veterinary services (walking hours) Ave. time to reach to drinking water (walking hours) Ave. time to reach market (walking hours)
	Human	Knowledge/skill	% of HH heads with no formal education % ofHH heads not received climate specific training % ofHH heads not received health extension service
		Livelihood strategy	% ofhouseholds did not work in non-farm income % ofHH did not work in off-farm income activity % of HHs that majorly depend on agriculture as source of income % of HHs that did not migrate outside the community
		Socio-demographic	% of female head households Dependency ratio Farm experience (inverse)
	Social	Social networks	% of households do not help others % of households who received help from others % of HHs not part of the *debo*-working together % of HHs not involve in cooperative membership

Annex 4.2Conversion factor of various classes of livestock to TLU

Animal Category	Tropical Livestock Unit TLU)
Bulls/Oxen	1.42
Cows	1
Heifer	0.78
Calves	1
Sheep	0.2
Goats	0.2
Horses	0.8
Mules	0.7
Donkeys	0.8
Poultry	0.04

Source: Strock *et al*. (1991)

Annex 4.3Conversion factor for Adult Equivalent (AE)

Sex

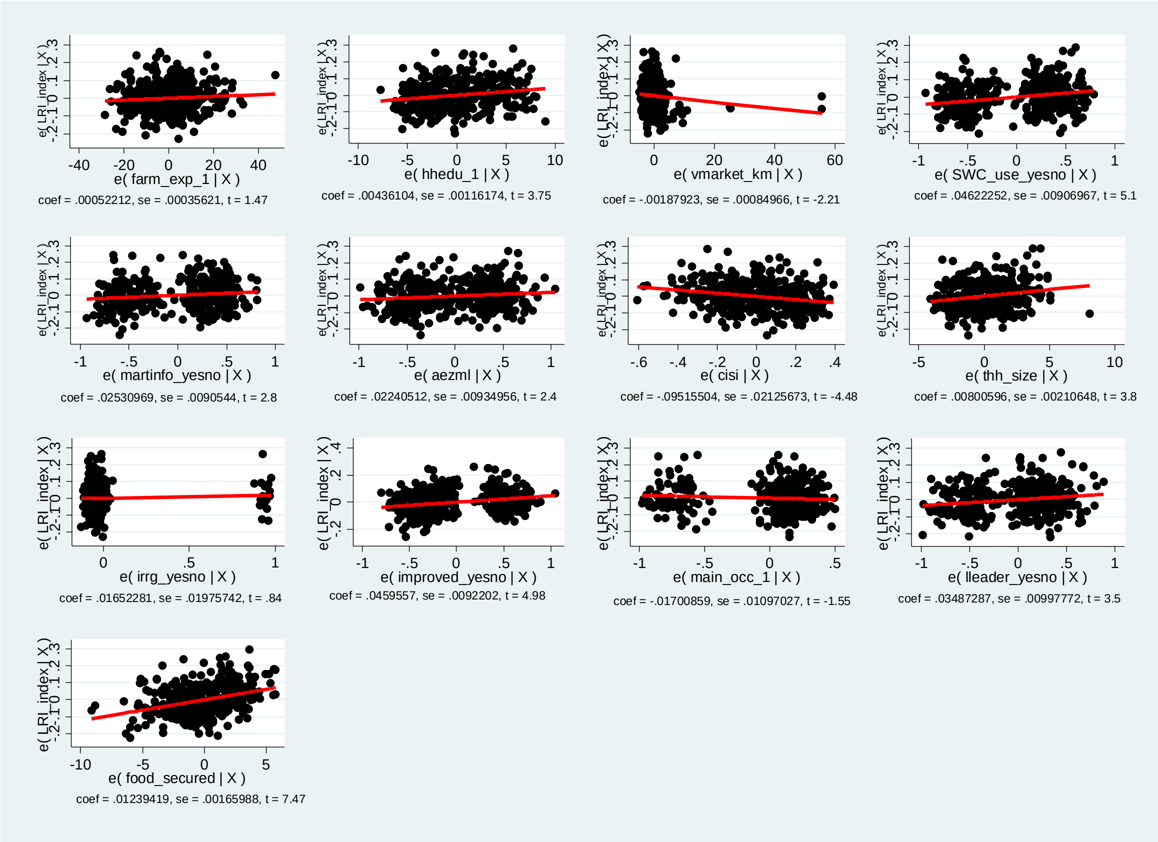
Age group (years)	Male	Female
<10	0.60	0.60
10-13	0.90	0.80
14-16	1.00	0.75
17-50	1.00	0.75
>50	1.00	0.75

Source: Strock *et al*. (1991)

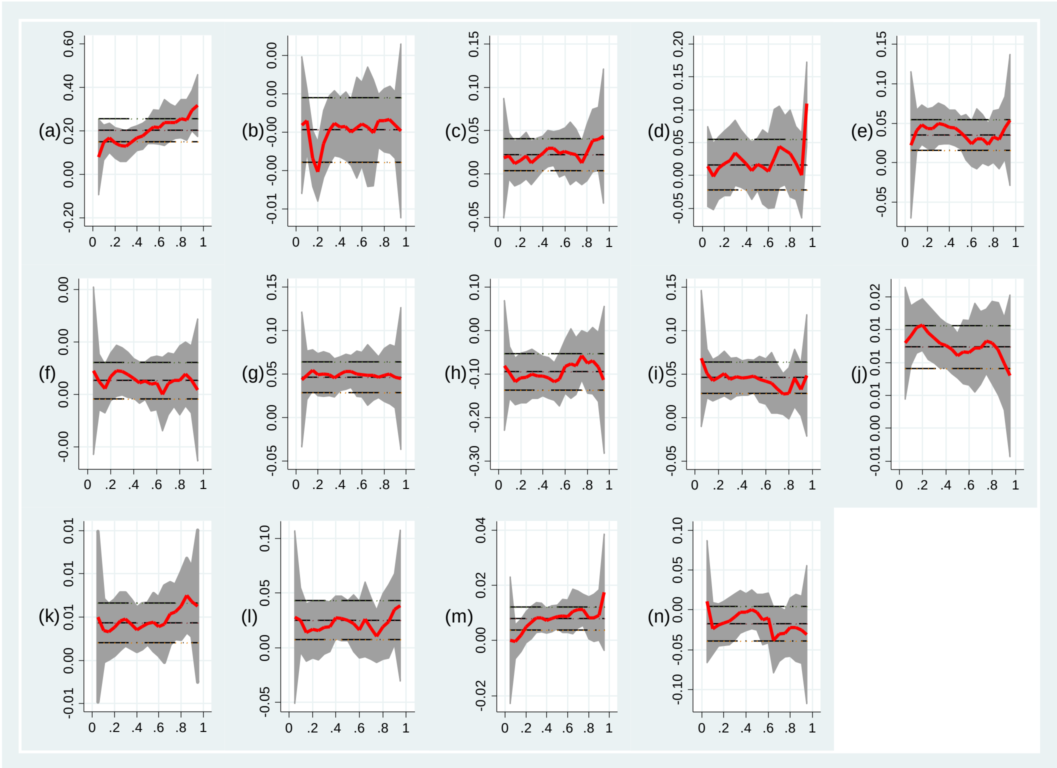
Annex 5.1 Tests for Gaussian assumptions

No.	Gaussian Assumption	Test conducted	Chi^2 value	P-value	Decision
1	Error terms from OLS regression of LRI on its determinants have constant variance.	Ho: Constant variance	21.18	0.0000	Error terms exhibit heteroscedasticity that may contribute to skewed distribution of LRI
2	Error terms from OLS regression of LRI on its determinants are normally distributed.	Ho: error terms are normally distributed	7.71	0.0212	OLS may fail to capture the effect of determinists on LRI

Annex 5.2Graphical method of detecting outliers



Annex 5.3Ordinary least squares and quantile regression coefficients for different predictors of livelihood resilience index



The figure stands for the explanatory variables used in the quantile regression where the y-axis represents the coefficients while the X-axis indicates the quantiles. Each letter represents as, (a) intercept, (b) village market distance, (c) midland agro-ecology, (d) irrigation use, (e) role in the community, (f) farm experience, (g) soil and water conservation, (h) climate shock index, (i) use of improved seed, (j) food secure months, (k) education, (l) market information, (m) family size and (n) main occupation, respectively.

Endnotes

[1] Resilience is acknowledged in a multitude of ways in SDG targets proposed. For example, target 1.5 stands for the core resilience target, which stipulates as: "By 2030 build the resilience of the poor and those in vulnerable situations, and reduce their exposure and vulnerability to climate-related extreme events and other economic, social, and environmental shocks and disasters." (see also Bahadur *et al.*, 2015a p. 2).

[2]*El Niño* and *La Niña* denote to the warming and cooling of sea-surface temperatures(SST) in the equatorial Pacific Ocean, respectively that influence atmospheric circulation and consequently rainfall and temperature in particular areas in the world (IPCC, 2014).

[3] MoA (2000) classified traditional agro-ecological Zones of Ethiopia into five major categories based on altitude (meters above sea level), rainfall (mm/year), and temperature (mean annual temperature in °C). Namely, 1) *Bereha* (dessert) <500 m.a.s.l, <200mm/year, and > 27.5 °C; 2) *Kola* (lowlands), 500-1500 m.a.s.l, 200-800mm/year, and 27.5-20 °C; 3) *Wenadega* (midland), 1500-2300 m.a.s.l, 1200mm/year, 20.0-17.5/16.0 °C; 4) *Dega* (highland), 2300-3200 m.a.s.l, 900-1200 mm/year, and 17.5/16.0 -15.5 °C; and 5) *Wurchi* (upper highland), 3200 plus m.a.s.l, 900-2200 mm/year, and <11.5 °C (p.3).

[4] Other methods include, Department for International Development (DIFD) and TANGO's consultant resilience framework (Smith *et al.*, 2015), Livelihoods Change Over Time (LCOT) model by Tuft University (Maxwell *et al.*, 2013) and Community Based Resilience Analysis (CoBRA) framework (UNDP, 2014), among others.

[5]Shock is an event that can trigger a decline in well-being, which can affect individuals (illness and death), a community, a region, or even a nation (natural disaster and macroeconomic crisis) (World Bank, 2000). It is also taken as a sudden event that impacts on the vulnerability of a system and its components. The shocks can be *idiosyncratic shocks,* which affect individuals or households, including, illness, injury, death, job loss, crop failure, and loss of transfer. While, *covariant shocks* affect groups of household, communities, regions or even entire countries such as armed conflict, financial crisis, changes in food price, drought, flood and social unrest (UNDP, 2011). In this study, multiple environmental or climate related shocks were considered, including floods, droughts, crop failure, crop pest and disease, livestock disease, and human disease to develop a climate induced shock index (CISI) to explore farmers' livelihood vulnerability, on one hand and livelihood resilience capacities, on the other hand. The index was computed using (UNDP, 2007) normalization process where the CISI was calculated as the sum total of all the observed shocks and divided by the number of shocks to lie between zero and one.

[6] A stress is a long-term trend that undermines the potential of a given system and increases the vulnerability of actor within it (UNDP, 2011).

[7]This approach discusses resilience of whom (i.e., individuals, households, communities, national governments), *resilience to what* (e.g., the shock or stress to which the system is exposed), *the degree of exposure* (e.g., large-scale versus disparity of exposure), *sensitivity* (ability to cope in the short term and adapt to the changing situations over the long term, and finally, assess the system's capacity to respond to the disturbance (e.g., survive, cope, recover, learn, transform) (Brooks *et al.*, 2014).

[8] In this study, resilience components studied include, *resilience for whom?* (e.g., farm households' livelihood resilience); *resilience to what*? (climate induced multiple shocks such as floods, droughts, crop failure, crop pest and disease, livestock disease, and human disease among others); *the degree of exposure/scale* (three agro-ecological settings in Wolaita Zone, Southern Ethiopia); sensitivity (explores absorptive, adaptive, and transformative capacities); system's capacity to respond to the disturbance/shocks (e.g., it was anticipated that households followed either the resilience pathway/positive outcome or the vulnerability pathway/negative outcome) in integrated ways (see also Cutter, 2016).

[9] The third administrative state structure in the region, next to *Zone* or the fourth in the country.

[10] It is the average number of people per square kilometer.

[11]Ontology: It is part of philosophy that studies the essence of 'being'; from the Greek óntos (to be, being) and lógos (discourse, reflection) and *epistemology* (whether or how we can gain knowledge of that reality).reflection on scientific knowledge, from the Greek epistéme (certain knowledge). In other words**,** epistemology deals with our understanding of knowledge. I.e., how we come to know the world as a site for research and analysis (Jupp, 2006; Shaw *et al*., 2010).

[12] A 'cluster of beliefs and dictates which for scientists in a particular discipline influence what should be studied, how research should be done, how results should be interpreted, and so on' (Bryman, 1988, p. 4). The idea of 'paradigm' has ancient origins in the history of philosophical thought. The notion was used both by Plato (to mean 'model') and by Aristotle (to mean 'example'). The term is mainly linked with Thomas Kuhn and his research concerning the history of science, discussed in the book *TheStructure of Scientific Revolutions* (1962/1996) (See Jupp, 2006).

[13] Creswell (2012) identified six types of mixed research design strands. These include, 1) convergent (or parallel or concurrent) mixed methods design. This is to simultaneously collect both quantitative and qualitative

data, merge the data, and use the results to understand a research problem; 2) explanatory sequential mixed methods design. This type consists of first collecting quantitative data and then collecting qualitative data tohelp explain or elaborate on the quantitative results; 3) exploratory sequential mixed methods design, which follows the steps of first gathering qualitative data to explore a phenomenon,and then collecting quantitative data to explain relationships found in the qualitativedata; 4) transformative mixed methods design, which deals with using one of the four designs (convergent, explanatory, exploratory, or embedded), but to encase the design within a transformative framework or lens; 5) multiphase design, which is a complex design that builds on the basic convergent, explanatory, exploratory, and embedded designs. This mostly occurs when researchers examine a problem through a series of phases or separate studies; 6) embedded design is a procedure used to collect quantitative and qualitative data simultaneously or sequentially, but to have one form of data play a supportive role to the other form of data (Creswell, 2014).

[14]Eight members of the teaching staff at Wolaita Sodo University who speak the local language along with farm level agricultural extension agents were involved in the data collection between February to April 2017 in each AEZ.

[15] 20 World Meteorological Organization's (WMO) Expert Team on Climate Change Detection and Indices (ETCCDI) extreme climate events indices, Exposure Index, Sensitivity Index (SI), Livelihood Vulnerability Index (LVI), Climate Induced Shocks Index (CISI), Livelihood Diversification Index (LDI), Household Asset Index (HAI), Productive Assets Index (PAI), Household Dietary Diversity Score (HDDS), Precipitation Concentration Index (PCI), Standardized Rainfall Anomaly (SRA), Adaptive Capacity Index (ADCI), Absorptive Capacity Index (ABCI), Transformative Capacity Index (TCI), Livelihood Resilience Index (LRI) and others were used to present the findings of the study.

[16]This is because, despite the heterogeneous conditional distribution of the variable(s), OLS introduces linearity, homoscedasticity, no multicollinearity, no significant outliers and normally assumptions.

[17] In non-Gaussian distributions, sample mean's asymptotic variance is larger than sample median's asymptotic variance.

[18] After data transformation (UNDP, 2007), both the past and future subjective resilience capacity indices are computed as the summation of all shocks to each time period (Flood, drought, crop failure, crop pest and disease, livestock disease, and human disease).

[19]Food aid, in the past and present, refers to food distributions in response to specific emergency needs. The PSNP provides regular, multi-year transfers to households for six-months of the year. In most regional states, the transfer is made in the form of cash payments, for which labor contributions are required (Cochrane & Tamiru, 2016).