# Households' Vulnerability, Food Insecurity and Risk Coping Strategies under the Changing Climate: in the semi-arid highlands of Eastern Tigray, Northern Ethiopia

**Hailay Tsigab Kahsay**

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

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

**Addis Ababa University**
**Addis Ababa, Ethiopia**
**July 2020**

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**Addis Ababa University**
**Addis Ababa, Ethiopia**
**July 2020**

## Declaration

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

Name: **Hailay Tsigab Kahsay**
Signature: _________________
Date: July 20, 2020
Place: Addis Ababa
Date of submission: July 20, 2020

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

Main supervisor's name: Dawit Diriba (Ph.D.)
Signature: _______________________
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# Dissertation Approval

## Addis Ababa University

## School of Graduate Studies

This is to certify that the dissertation prepared by **Hailay Tsigab Kahsay** entitled **"Households' Vulnerability, Food insecurity and Risk Coping Strategies under the Changing Climate: in the semi-arid highlands of Eastern Tigray, Northern 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:

___________________________ ___________ ______________

Chair, Examining Committee Signature Date

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Chair of the Department or Graduate Program Coordinator

___________________________ ___________ ________

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# Dedication

*I dedicated this work to my family whose unprecedented affection was a source of my courage throughout the Ph.D. study*

# Households' Vulnerability, Food insecurity, and Risk Coping Strategies under the Changing Climate: in the semi-arid highlands of Eastern Tigray, Northern Ethiopia

## General abstract

*The main objective of this research is to analyze farm households' perceptions, livelihood vulnerability, and risk coping strategies to the changing climate and variability. The multistage sampling method was applied to collected data from 358 rural households in Hawzen and Irob districts corresponding with the 1983-2016 meteorological data of rainfall and temperature. The non-parametric Mann-Kendall test and the Sen's slope estimator, principal component analysis, and Foster-Greer-Thorbecke techniques were employed to analyze rainfall and temperature trends, household's vulnerability, and decompose food security status. The econometric model utilized includes Heckman probit selection, three-step Feasible Generalized Least Square, and multivariate probit regression. The results revealed that nearly 95 and 89 percent of farmers perceived a decreased annual rainfall and an increasing temperature consistent with the meteorological data in Hawzen and Irob districts, respectively. Farmers' choice of soil and water conservation adaptation strategy is significantly influenced by age, household size, access to extension services, off-farm activities, weather information, and rainfall trend. The Household Vulnerability Index reveled that households from Hawzen were relatively less vulnerable than Irob. Besides, 27 percent of households were categorized under highly vulnerable group. Holding the food poverty line the number of households with high vulnerability to food insecurity (93 percent) was higher than the current food-insecure (84 percent).Expected future food consumption expenditure was increased with dependency ratio, livestock size, irrigation potential, livestock death, energy cost, and positive annual rainfall trend in Degamba Kebele. The multivariate probit regression model showed complementary and substitutability among the three risk coping strategies to smooth food consumption fluctuation. The likelihood of choosing these risk coping arrangements significantly increases among male-headed households, access to credit, motor road, input-output market, community-based health insurance, TV/radio ownership, and annual rainfall trend in Irob. Thes results have important policy implications such as promoting updated weather information through extension services to create resilience livelihood. The policy should focus not only on current food insecurity but also on those households more likely to be food insecure soon and encouraging the role of rural local institutional arrangements.*

**Keywords**: Climate change, perception, vulnerability, food security, risk coping strategy.

## List of original papers

**Paper 1.** Hailay *et al*. (2019).Farmers’ Perceptions of Climate Change Trends and Adaptation Strategies in Semiarid Highlands of Eastern Tigray, Northern Ethiopia. *Advances in Meteorology*, *2019*, https://doi.org/10.1155/2019/3849210 **Published**

**Paper 2.** Hailay *et al*. (2020).Households' livelihood vulnerability to the changing climate and variability. *Journal of Environment Development and Sustainability*, Springer (**revision submitted**)

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# Acronyms

| | |
|---|---|
| AE | Adult Equivalent |
| AEZs | Agro-Ecological Zones |
| ANOVA | Analysis of Variance |
| $^0$C | Degree Celsius |
| $CO_2$ | Carbon dioxide |
| CC | Climate Change |
| CSA | Central Statistics Authority |
| CV | Coefficient of Variation |
| DFID | Department for International Development |
| EGV1 | Eigen Value Greater than 1 |
| FAO | Food and Agricultural Organization |
| FDRE | Federal Democratic Republic of Ethiopia |
| FGT | Foster-Greer-Thorbecke |
| FGLS | Feasible Generalized Least Squares |
| FGD | Focal Group Discussion |
| FO | Field Observation |
| HH | Household Head |
| HVI | Household Vulnerability Index |
| IPCC | Intergovernmental Panel for Climate Change |
| KI | Key Informants |
| KM | Kilometer |
| MKT | Mann-Kendall Trend |
| m.a.s.l | Meters above Sea Level |
| mm | Millimeter |
| MNL | Multinomial logit |
| MoA | Ministry of Agriculture |
| MVP | Multivariate probit |
| NGOs | Non-Governmental Organizations |
| NMAE | National Meteorological Agency of Ethiopia |
| OLS | Ordinary Least Squares |

| | |
|---|---|
| PCA | Principal Component Analysis |
| PhD | Doctor of Philosophy |
| PSNP | Productive Safety Net Program |
| SD | Standard Deviation |
| SDGs | Sustainable Development Goals |
| SLF | Sustainable livelihood framework |
| SRA | Standardized Rainfall Anomaly |
| SSA | Sub Saharan Africa |
| T max | Max Temperature |
| T mean | Mean Temperature |
| T min | Min Temperature |
| TLU | Tropical Livestock Unit |
| UNDP | United Nations Development Program |
| USD | United States Dollar |
| VIF | Variance Inflation Factor |
| WFP | World Food Program |
| WMO | World Meteorological Organization |
| WSC | Water and Soil Conservation |

# Chapter One

## 1 General Introduction

### 1.1. Background of the study

Climate change and its antecedent impacts have become unequivocal urgent global challenges as a result of anthropogenic emissions of greenhouse gases and natural factors (Intergovernmental Panel on Climate Change (IPCC), 2013). The scientific community recognized that climate change is true and its impacts have become progressively unlike a few decades ago (Pachauri and Reisinger 2008; Abid *et al*., 2016). Climate change-related extreme weather events such as floods, erratic rainfall, and global warming adversely influencing the global economy, particularly the livelihood of the poor households' disproportion with spatial areas (Corcoran, 2016; Escarcha *et al.,* 2019). These adverse extreme climatic events caused multiple threats to agricultural production, food insecurity, public health, the migration crisis, and vulnerability of species (Arora-Jonsson, 2011; WHO, 2012; Fortini and Dye, 2017). Therefore, extreme climatic threats and rising income disparity between the poor and the rich are among the major environmental and human development challenges of the twenty-first century facing the global society (Maru *et al.,* 2014; Driedonks *et al.*, 2016).

Climate change is an exogenous factor expected to affect temperature and rainfall patterns which reinforce most ecological processes (Fischer *et al.,* 2013; Abrams *et al.,* 2018). Global climate change is a change in surface air temperature and rainfall over a long period while climate variability is a short term variation of these parameters (Mahato, 2014). The Global Mean Surface Temperature (GMST) increased by 0.89 degree Celsius ($^0$C) during 1901-2012 caused by human action greenhouse gas accumulations combined with environmental degradation (IPCC, 2013). As a result, the global average temperature will warm between 1.48$^0$C and 5.88$^0$C by 2100 that amplifies the frequent extreme weather events (IPCC, 2001). Furthermore, the GMST raise between 1.5$^0$C-4.5$^0$C by the late 21$^{st}$century at a rate of 0.2$^0$C each decade (Bhattacharya, 2019). The global annual average temperature is expected to be 2ºC above pre-industrial levels by 2050 which intensified extreme climatic events (IPCC, 2007). Therefore, the issue of climate change has transformed into a development agenda than a simple environmental issue by mainstreaming into economic growth and food security components in the international development plan.

Developing countries, particularly sub-Saharan Africa (SSA) farming system is conditioned by climate regulated rain-fed agriculture threaten the livelihood of the poor households. About 80 percent of food consumption in Africa and Asia produced by 75 percent of smallholder farmers' agricultural land (FAO, 2013; Samberg *et al.,* 2016). However, erratic rainfall and extreme weather events cause agricultural drought and more likely to continue due to natural and human actions (Kuenzer and Renaud, 2012; Nadin *et al.*, 2015). In Africa climate assessment studies revealed that rural households are principally vulnerable to climate change and variability impacts (IPCC, 2014; Orimoloye *et al.*, 2019). Africa warming is above the global annual mean warming over the continent in all seasons (IPCC, 2007). As a result, a temperature rise of 3-4$^0$C could reduce crop productivity by 15-35 percent of the continent (FAO, 2009).

In Africa, annual rainfall is expected to fall in most of the region, though it projected to increase in eastern Africa (Brown *et al*., 2007). SSA rainfall could drop by 10 percent by 2050 which further worsens consumption and income fluctuation (Barrios *et al.*, 2010). The maximum and minimum temperature anomalies will be warmer up to 3.7°C and 2.76°C than the baseline period during the 21$^{st}$ century in East Africa (Gebrechorkos *et al*., 2019). Therefore, the frequent social and food crises in Africa, which demand foreign food aid caused fully or partially by extreme weather events (Haile, 2005).

In Ethiopia, the mean annual temperature increased by about 1.3°C between 1960 and 2006, with an average rate of increased by 0.28°C per decade, though annual and seasonal rainfall changes showed a mixed trend (Conway and Schipper, 2011; IPCC, 2013). Climate variability and persistent meteorological droughts damaged the rain-fed reliant agriculture sector in Ethiopia. In Ethiopia, drought had revealed an increasing trend since the 19th century (World Bank, 2005). These adverse climate change could be causing the Ethiopian GDP 8-10 percent less than in the absence of climate change by 2050 (Robinson *et al*., 2013). Furthermore, it undermines the GDP growth of the country between 0.5 - 2.5 percent annually (McSweeney *et al.*, 2010).

The Earth has confronted a fresh set of interrelating challenges (Evans, 2009). The world population of 6.06 billion in 2000 will grow to 8.3 billion in 2030 and 9.3 billion people in 2050 congruently global food demand will expect to increase 70 to 100 percent in 2050 (World Bank, 2008; Godfray *et al.*, 2010). However, between 2000 and 2050, global food production is predicted to increase by 85 percent below the required demand (Calzadilla *et al.,* 2014). The expected, cereal production in developing countries will be more than double by 2050 due to the rapid population growth. Globally, without climate change, the number of people faced with hunger would be predicted to decrease by around 406 million in 2050, but climate change impacts are expected to raise this number by 70 million due to insufficient food production (Wiebe *et al.*, 2019).

With the climate change scenario, the total calories available in 2050 will be lower relative to the year 2000 worldwide, while it will decline to 10 percent in developing countries in the same year (Nelson *et al.*, 2009). According to these authors' predictions, child malnutrition will increase by 20 percent in 2050 relative to a world with no climate change. Jones and Thornton (2003) also suggested that warming and drying weather reduce crop production worldwide by 10-20 percent in 2050. Subsequently, the global agricultural production increase will be reduced by 0.9 percent in 2050 compared with 2.3 percent growth per year since 1961 (FAO, 2003).

Approximately 70 percent of the population of developing countries depends on farming as the main source of livelihood that threatened by extreme adverse climate events (Yadav *et al*., 2015). SSA annual cost of drought estimated 1-13 percent of the GDP (Low, 2013). Therefore, the current scenarios for "*business-as-usual"* farming under climate change exacerbated food security challenges by 2050 (Wiebe *et al*., 2019). In some countries of Africa, agricultural production from rain-fed agriculture may decline to 50 percent in 2020 though 93 percent of their farmed land is rain-fed agriculture (Solomon *et al.*, 2007; FAO, 2018). Africa's rain-fed farm production could decline by 50 percent in 2020 under climate change scenarios (Boko *et al*., 2007). Further, the World Food Program (2008) found that adverse climate change suffers more than 100 million people into extreme poverty by 2030. This adverse impact of climate change decelerates the global effort to end hunger, achieve food security, and improved nutrition in 2030. Furthermore, ending climate change impact is one of the 17 goals of the 2030 Agenda for Sustainable Development adopted by the UN.

Ethiopia is often mentioned as one of the most drought-prone and extremely vulnerable to climate change since 250 BC, which has damaged the national economy severely (Ramakrishna and Demeke, 2002; Conway and Schipper, 2011). Granting to the Global Climate Risk Index 2017, Ethiopia was the fifth most weather-related affected country in Africa during 1996-2015 (World Bank, 2010). The 1984-1985 droughts in Ethiopia reduced agricultural output by 21 percent, equivalent to a 9.7 percent fall in GDP (World Bank, 2006). UNDP (2011) revealed that Ethiopia would lose 7-8 percent of its GDP annually due to climate change impacts that mainly influence the livelihood of poor households. The 2016 *El Niño* weather event in Ethiopia is one of the worst droughts on record which exposed 10.2 million people into food insecurity (FAO, 2016).

Rural households have employed various strategies to cope with adverse weather shocks. These coping strategies including liquidate livestock assets to earn additional income for consumption smoothing (Adimassu *et al.,* 2014), introduce farm-level coping strategies (Alemayehu and Bewket, 2017; Gao and Mills, 2018) and diversifying livelihood sources (Mentamo and Geda, 2016). However, these studies overlooked rural institutional arrangements risk coping strategies through which they deal with climate change impacts.

Poor rural households in developing countries, including Ethiopia adopt local institutional arrangements to maintain food consumption fluctuation (Agrawal, 2008; Matewos *et al.,* 2019). "Institutional arrangements structure risks and sensitivity to climate hazards, facilitate or impede individual and collective responses, and shape the outcomes of such responses" (Agrawal 2008:8). Institutions organize climate change impacts and vulnerability, mediate between individual and collective actions, and offering resources to facilitate the coping measures (Agrawal, 2010). Nevertheless, risk coping strategies through local social networks may not be sufficient due to lack of information and resources during covariant climate-induced shocks that requests public intervention through safety net programs (Thwaites *et al*., 2013).

### 1.2. General problem statement

There is ample empirical evidence about the impact of climate change and the factors that determine adaptation strategies in northern Ethiopia (Shiferaw *et al.,* 2014; Alemayehu and Bewket, 2017; Mersha and Van Laerhoven, 2018), among others. To the extent of my cognition, though recently there are attempts by Deressa *et al.* (2011); Asrat and Simane (2018), less attention has been paid to examine empirically smallholder farmers' perception and its influence on adaptation strategies. Because, farmers' perceptions and indigenous knowledge have an indispensable role in the process of coping and adaptation strategies to climate change impacts (Ramos and McLean, 2012; Abid *et al.,* 2015). Farmers use different adaptation measures based on the obtained and access to livelihood capital. However, most of the adaptation measures in developing countries remained unsuccessful because farmers' perceptions were ignored in the process of adaptation planning (Alam *et al.,* 2017). In Africa climate change risk perceptions are traditional and different from those of developed countries, as a result, there is a rudimentary understanding of the complex link between farmer's perception and adaptation measures (Steynor and Pasquini, 2019). Therefore, this study helps to fill this gap by investigating the influence of farmers' perceptions on adaptation decisions to climate change impacts. Despite, recently farmers' perceptions and their influence on adaptation decision to ease climate change impacts have been receiving increasing attention at various scales (Hundera *et al.,* 2019).

Many studies in Ethiopia analyzed livelihood vulnerability to climate change and variability at a macro level (Deressa *et al.,* 2008; Gebrehiwot and Van Der Veen, 2013; Simane *et al.,* 2014). However, results from these studies are highly aggregated hence the parameters have little benefit to measure the level of household vulnerability given the enormous heterogeneity existed among the households. Macro-level vulnerability assessments hide individual household's vulnerability by aggregating various heterogeneity livelihood capitals (Skjeflo, 2013). Measuring vulnerability to climate change and variability at the household level is useful to exactly determine the degree of exposure and adaptation capacity (Adu *et al.,* 2018).

Furthermore, livelihood vulnerability to climate change and variability is divergent among different agro-ecological systems and socioeconomic groups in rural Ethiopia (Simane *et al.*, 2014; Tessema and Simane, 2019). For example, households in lowland were highly vulnerable than highland counterparts due to low adaptive capacity in the central rift valley of Ethiopia (Mekonnen *et al.*, 2019). Moreover, IPCC (2007) unveiled that climate change impacts are asymmetrically spread among different regions, ecosystems, and levels of economic development. Hence, disregarding livelihood and agro-ecological differentiation affects the implementation of context-specific policy interventions to fight climate change impacts. To fill this gap this study constructs various indices to measure the degree of household's vulnerability to the changing climate. Recently, only a few studies have focused on the household level vulnerability to climate change and variability in Ethiopia (Tesso, 2013).

Dynamism is an essential feature of food insecurity (Chaudhuri, 2003). Thus, *ex-post* food insecurity analysis fails to indicate the propensity of becoming or remaining food insecure over time. Vulnerability to food insecurity is an *ex-ante* approach apart from '*the who is who*?'

categorization of current food insecurity status. The majority of studies in Ethiopia give a greater focus on current food security status overlooking the vulnerability to food insecurity analysis (Bishop, 2010; Coll-Black, 2012; Maxwell *et al.*, 2014; Agidew *et al.*, 2018) to name a few. However, these empirical studies cannot be used as a proxy to measure vulnerability to food insecurity because of current food insecurity unable to account for the number of households becoming food-insecure shortly (Capaldo *et al*., 2010).

Moreover, empirical results in Ethiopia confirmed that rural household's food consumption is unstable and changing over time mainly due to extreme weather events (Bogale, 2012; Maxwell *et al*. 2014; Sileshi *et al.,* 2019). In rural Ethiopia, a one-period drought in the last five years has a current 20 percent lower per capita food consumption (Dercon *et al.,* 2005). This implies that food insecurity could consider as a dynamic concept than a static although its empirical measurement is challenging due to appropriate data constraints (Capaldo *et al.* 2010). Therefore, this study is motivated by the thought that, given the pervasive nature of food insecurity in the study area, a static measure of food insecurity is inadequate in terms of policy interventions and did not capture all the dimensions of food security.

The central challenge rural households' face in developing countries is how they sustained their food consumption under persistent adverse climatic shocks. Farm households in developing countries, including Ethiopia use multiple risk coping strategies to moderate climate change impacts (Trærup and Mertz, 2011; Adimassu and Kessler, 2016; Alemayehu and Bewket, 2017). Successful adaptation mechanisms among rural households depends mainly on the nature of existing formal and informal rural institutions through facilitate collective action during uncertainty and perform together for a common interest (Agrawal, 2010).

Rural institutions have a crucial function for risk management and coping strategies ranges from formal insurance to informal resource sharing mechanisms (Adger 2006). Public institutions play a dominant function in implementing climate change adaptation programs and build livelihood resilience in SSA (Zallé, 2019). But, when public institutions are absent social networks are helpful to moderate household's vulnerability from extreme shocks (Adger, 2003). Rural farmers depend on kinship relations and other social networks to disseminate climate change information under imperfection market.

In line with this premise, Ethiopia introduced the Productive Safety Net Program (PSNP) since 2005 to provide multi-annual transfers to chronically food-insecure households to break the trap of food insecurity. Moreover, resource sharing is a common traditional social support used in response to idiosyncratic shocks in developing countries, including Ethiopia (Smucker and Wisner, 2008; Deressa *et al.*, 2009). In Ethiopia, rural institutions have played a critical function to facilitate adaptation to climate change although few emphases have been devoted compared with other forms of risk coping strategies (Matewos, 2019).

As a result, the role of rural institutional arrangements to smooth household's food consumption during climate-related extreme weather events has been concealed several issues. Specifically, among the basic essential aspects received little attention is the factors determine household's decision among the different institutional arrangements and the correlation existed among the various institutional arrangements when they employed jointly as risk coping strategy (Bisaro *et al.*, 2017; Boansi *et al.*, 2017).

## 1.3. Objective and research questions of the study

### 1.3.1. General objective

The main objective of this study is to critically analyze rural households' perceptions, livelihood vulnerable, and risk coping strategies to the changing climate in the semiarid highlands of Eastern Tigray, northern Ethiopia.

### 1.3.2. Specific objectives

Inline to the general objective, specific objectives are placed as follows:

1. To investigate farmers' perception and climate change trends and its influence on adaptation strategy decisions;
2. To measure households livelihood vulnerability to climate change and variability;
3. To decompose and analyze factors determine households' vulnerability to food insecurity;
4. To examine the factors that affect rural households' risk coping mechanisms to reduce extreme climatic events.

### 1.3.3. Research questions

To address the above objectives the following research questions were developed:

1. Do farmers' perceptions of climate trends consistent with meteorological data? What factors determine households' perception and adaptation decision to climate change?
2. Which household groups are most vulnerable to climate variability? Who are the most vulnerable households to climate change and variability?
3. How vulnerable are households to food insecurity? What factors determine households' vulnerability to food insecurity?
4. What are the major shocks households experienced over the last ten years? What factors determine households' decision to choose *ex-post* risk coping measures?

## 1.4. Significance of the study

The findings of this study provide important empirical information to researchers, local policymakers, and academic experts on farmers' perception, livelihood vulnerability, and risk coping mechanisms under changing climate. Currently, the Ethiopian government is prioritizing building a climate-resilient, green economy in the context of sustainable development and realizing the vision of becoming a lower-middle-income country by 2025 (MoFED, 2010). Therefore, this study has provided important benefits for decision-makers and practitioners to develop alternative policy interventions and adopt as a benchmark for further study in the study area.

Generally, the results of this study would have the following redound significances: The semi-arid highland of Eastern Tigray is characterized by extreme climate events, erratic rainfall, and frequent droughts which cause persistent severe food insecurity and welfare declines. Therefore, this study is helpful to know the variability of rainfall and temperature, degree of households' livelihood, and food insecurity vulnerability. Moreover, it helps to draw the attention of subsequent researchers on the functions of rural arrangements, which have been not enough studied, as risk coping measures in the study area in particular and Ethiopia in general.

This may further attract the interest of policymakers and researchers to investigate the use of rural arrangements mechanisms to keep food consumption fluctuation during climatic stress events. Overall, the findings of this study will assist local and regional policymakers to understand the extent of households' livelihood and food insecurity vulnerability the risk coping decisions to deal with adverse shock using rural arrangement institutions.

### 1.5. Scope and limitation of the study

The primary data survey confined to cross-sectional data generated from households lived in Hawzen and Irob Districts. Consequently, the overtime dynamics of food insecurity which required panel data were analyzed using cross-sectional data. The secondary data on annual rainfall and temperature covered the time between 1983 and 2015/6 due to data available in both districts and four *kebeles*. As a result, rainfall and temperature trends didn't analyze for each household at the plot level. The empirical findings obtained from this study inferred to the other semi-arid highlands of Eastern Tigray since it shared some related socioeconomic, biophysical, AEZs, and institutional environments.

Constructing a single Household Vulnerability Index (HVI) required to measure adaptive capacity, sensitivity, and exposure subcomponent variables. But it is very difficult to exhaustively list and measure all the components of vulnerability directly. Hence, this study only included variables that can easily measure objectively holding the integrated vulnerability assessment framework, but it does not cover the variables like the quality of education, health, and political dimensions of vulnerability under this study. Likewise, among the multiple food security measurement parameters, the food energy intake method was considered excluded from the non-food items. Moreover, the study is only limited to the rural areas of the two sample districts.

### 1.6. Study area description

Arid, semi-arid, and dry sub-humid climate accounts for 71 percent of the total land area of Ethiopia (Ambachew *et al.,* 2014). The climate of northern Ethiopia is tropical semi-arid susceptible by soil degradation and high rainfall variability due to biophysical and socioeconomic factors (Nissan *et al*., 2004). The mean summer rainfall ranges from 300 to 700 mm with temporal and spatial fluctuation (Dejenie *et al.,* 2012). The length of the growing period (the period between the onset and cessation of rain) ranges from 60 to 100 days in semi-arid Tigray highlands (Araya *et al*., 2010).

The study area, located in semi-arid Eastern highlands of the Tigray region, northern Ethiopia where households face critical covariate and idiosyncratic shocks. Geographically, the Districts are located between latitude 13°78′-14°18′N and longitude 39°18′-39°58′E and latitude $14^0$35'-$14^0$58'N and longitude $39^0$50'-$40^0$26'E respectively (Figure1.1). Climatically the semi-arid zone characterized by a heavy rainy season (June to August), small rainy season (March to May) and a major dry season (October to March) that are crucial factors for inter-annual fluctuations in crop production (Nyssen *et al.*, 2005; Conway and Schipper, 2011). The Eastern highlands receive an average yearly rainfall of 520-680 millimeter (mm) and annual average temperature ranges between16-$20^0$C with diurnal variations being larger than seasonal changes (Grum *et al.*, 2016).

The total population of Hawzen and Irob Districts were 127,265 (52 percent females) and 33,912 (51percent females), respectively in 2018. Out of these 93 and 95 percent of the population live in the rural areas relying mainly on a small-scale subsistent mixed agriculture system that integrates crop and livestock production. Hawzen District climatically 60 percent belongs to midland (*Woinadega)* 1500-2500 meter above sea level (m.a.s.l), 35 percent lowlands (*Kolla)* 500-1500 m.a.s.l) and 5 percent highland (*Dega)* 2500-3500 m. a.s.l. According to the country's traditional AEZ respectively. Likewise, Irob accounts for 75 percent midland, 15 percent high land, and 10 percent low land according to the country's traditional agro-ecological zone (AEZ), respectively. Rainfall is marked with a weakly bimodal pattern, with small showers of rain from March to May with a long rainy season in the summer from June to August. The most dominantly cultivated crops grown during the rainy season are mainly cereals such as Barley, Sorghum, Wheat, Maize, Teff, and Faba bean. Furthermore, oilseed, pulse, and vegetable crops are grown to supply food and generate income sources. The length of the growing season varies between 90 and 120 days (Birhane *et al*., 2017).

The total area covered estimated about 1,892.69 $km^2$ and 850 $km^2$ for Hawzen and Irob respectively characterized by rugged mountains, hills, high plateaus, and deep valley bottoms. The average elevation ranges from 2000 in Irob to 2243 meters m.a.s.l. in Hawzen, respectively. Both Districts are identified among the most vulnerable areas exposed to chronic food insecurity, adverse weather extreme events, and sever declining soil fertility. Specifically, during the 2015/16 El-Niño induced drought about 40 percent of the population of Hawzen District were vulnerable to food insecurity and 74 percent of the population of Irob were beneficiaries of the PSNP in the same year (Woreda Hawzen Finance and Planning Office, 2017; Woreda Irob Finance and Planning Office, 2017).

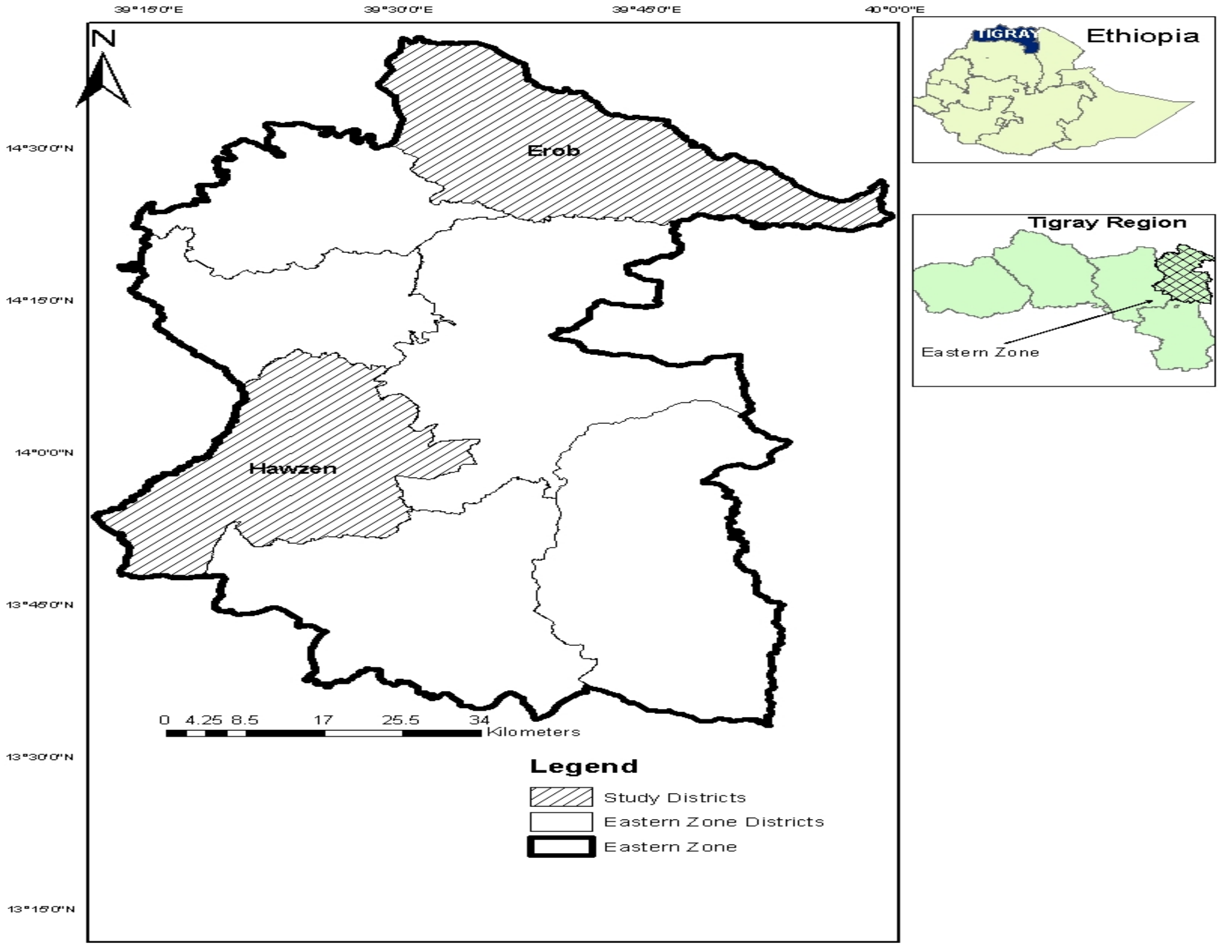


Figure 1.1 Location of the study areas

## 1.7. Theories and concepts of climate change, vulnerability, and risk coping

Currently, global climate change is one of the most controversial topics though a group of scientists does not have a general agreement on its exact meanings (Svensmark *et al.*, 2008; FAO, 2008). For instance, the World Meteorological Organization (WMO) (1992) refers to climate change as long-term changes in average weather conditions. United Nations Framework Convention on Climate Change (UNFCCC, 2007) defines climate change as human-induced changes in the climate system. Conversely, IPCC refers to climate change to any change in climate over time, whether due to natural variability or as a result of human activity (IPCC, 2007). Most of this change is only detected on astronomical or geological time scales considered as climate variability. But, an unequivocally these global scientific community confirmed the global climate has changed over time (Pachauri and Reisinger 2008).

Barry Saltzman has frequently been referred to as the “father of the modern climate theory” for his pioneer work to the General Circulation Model and meaning of climate change across a broad spectrum of time scales (Maasch *et al.*, 2005). Recently, Blast (2010) granted to the extant literature he compiled and analyzed seven theories of climate change that are mutually inclusive with each other. The critical development of the greenhouse theory of climate change was identified in 1896 by Arrhenius (Arnell *et al*., 2001). Climate forcing or mechanisms are factors that control climate change. Anthropogenic emissions of greenhouse gases (GHGs) are dominantly claimed for global warming (Ming *et al*., 2016).

Anthropogenic global warming (AGW) is the first theory of climate change that states human activity is responsible for the raise concentration of carbon dioxide ($CO_2$) and other greenhouse gases in the atmosphere particularly observed 50 years ago (Grasso,2009; Brooks, 2013). The ~0.7°C warming of the last century-and-a-half and ~0.5°C of 30 years ago partially or completely caused by man-made emissions of greenhouse gases (Bast, 2010). However, this evidence has not yet received adequate responses from the international community hence, it demands a crucial stage of verification (Grasso, 2009).

The bio-thermostat theory of climate change stated that negative feedbacks from biological and chemical processes fully or partially balance the positive feedbacks caused by rising $CO_2$ to keep temperatures in equilibrium. The removal of $CO_2$ from the atmosphere decreases active greenhouse gas however, the adjustment of the land surface causes heat energy of the atmosphere (Pielke, 2001). A rise in carbon sequestration by plants may be the best-known consequence of the rise in atmospheric $CO_2$. Carbon sequestration as a means of reducing the concentrations of the greenhouse gas in the atmosphere concentrated in the space with man-made emissions (Wingenter *et al.,* 2007).

The third theory of climate change suggested that changes in the formation and albedo of clouds create negative feedbacks that cancel out all or almost all of the warming effect of higher levels of $CO_2$. This has a vital role in regulating the earth’s energy budget and regulating anthropogenic climate changes. However, among the leading doubts in climate change is the net effect of changes in a cloud on radioactive heating of the earth (Zhu, 2007). London (1957) underscored clouds affect the radiation balance of the earth as a net cooling. Conversely, Lindzen *et al.* (2001) reported a strong inverse relationship between upper-level cloud area and the mean sea surface temperature of cloudy regions of the eastern part of the western Pacific.

The fourth theory of climate change suggested that climate change is not only the result of human activities but also greenhouse gas emissions through its transformation of the earth's surface due to human forces. These human forces including urban heat islands, aerosols (Earth's atmosphere pollutants) and ozone, deforestation, and Coastal development (Bast, 2010), among others. These human forces have local and regional effects on climate change like anthropogenic greenhouse gas emissions.

The fifth theory of climate change states that global temperature variability over the last 30 years, was due to the slow-down of the ocean's Thermohaline Circulation (THC). Oceans have important thermal roles in climate through the store and release heat seasonally and move heat around in its large-scale current systems (Winton, 2003). Further, this author indicates that ocean circulation warms the climate by reducing both the sea ice extent and the low oceanic cloud cover. Correspondingly, Winton et *al*. (2013) concluded that ocean circulation changes significantly act to warm the surface climate. Though the ocean's cause on surface climate changes is obvious through heat and carbon uptake, there is a lack of harmony on the role of the circulation response.

The six planetary motion theory of climate change suggested that the warming of the twentieth century observed by natural gravitational and magnetic oscillations of the solar system due to the planet's movement through space (Blast,2010). Finally, solar variability explains majority of all of the warming in the late twentieth century regardless of man-made greenhouse gas emissions. The IPCC 5th assessment report stated that the Sun has not been a major driver of climate change warming, in contrast, Holocene paleo-climatologic data (times 11,500 years ago to present) indicate that the Earth's climate is very sensitive to radiation (Lean and Rind, 1998; Geel and Ziegler, 2013). Broadly, the above theories can be categorized into human induced and natural (non-climatic) factor which are eclectically adopted to develop the conceptual framework.

The social psychology theory highlights that farmers' beliefs and attitudes can influence climate change impacts by motivate to take action using adaptation strategy (Clayton and Brook, 2005).

Similarly, most environmental sociological theorists suggested that experiencing with biophysical expressions and impacts on climate change will lead farmers to desire to adopt climate change (Arbuckle *et al.* 2015; Houser *et al.* 2017). Farmers may understand the local biophysical expressions and impacts of climate change. However, according to the political-economic context theory experiencing the effects of climate change has not led farmers to take action on climate change (Houser *et al.*,2019). This supports the express 'seeing is not believing' for farmers after recognizing their experience with climatic extremes many remained resistant to mitigate climate change impacts (Houser *et al.* 2017). The former two theories were adopted to conceptualized farmers perception in the present study.

Several authors have agreed that vulnerability is an extremely contested concept which conceptualizes in several ways when applied in various disciplines and contexts (Adger, 2006; Fussel, 2009). This inconsistency in meaning and measurement has the challenge to develop a single vulnerability assessment model (Vincent, 2004; Eakin and Bojorquez-Tapia, 2008). Originally the word vulnerable derived from Latin *vulnus*, meaning 'a wound', and *vulnerare*, 'to wound'. In Latin the term *vulnerabilis* used by the Romans to describe the state of a soldier lying wounded on the battlefield (Kelly and Adger, 2000). As a result, neither uniform definitions nor single methods exist to analyze vulnerability to climate change (Eakin and Luers, 2006; Panda, 2009). Rather, the conceptualization and operationalization of vulnerability depend on its suitability for the intended policy interpretation and implementation (Downing *et al.,* 2005). Lack of consensus on meaning and measurements of vulnerability caused a considerable difference in degree and rankings of systems vulnerability to climate change and policy intervention to moderate climate change impacts (Füssel, 2009).

Vulnerability to climate change is the degree to which a system is adversely damaged by climate-related stimuli and its incapability to absorb the adverse effects of climate change (IPCC, 2007). According to this definition, vulnerability involves three major components including adaptive capacity, sensitivity, and exposure (IPCC, 2007). Adaptive capacity is the ability of a system moderating vulnerability through managing sensitivity and exposure of climatic influences (Adger *et al.,* 2006*).* Adaptation does not achieve immediately rather the relationship between adaptive capacity and vulnerability depends on the time dimension and the nature of hazards under question (Brooks *et al.*, 2005). Adaptation based on purposefulness can be autonomous or planned adaptation (Smit *et al.,* 2000). An autonomous adaptation or reactive adaptation is a decision made by vulnerable people without direct interventions of a public agency to reduce climatic induced impacts (IPCC, 2001). However, Stern (2007) argued that an autonomous adaptation is inefficient and reduces planned adaptation to further marginalization of vulnerable groups. However, planned adaptation is the result of deliberate policy decisions by government agencies aimed at promoting appropriate and effective adaptation measures (Adger *et al*., 2007).

Exposure is the nature and degree to which a system is exposed to climate-related stimuli or socio-economic risks (Adger, 2006). Sensitivity is the degree to which a system is harmed directly or indirectly, either adversely or beneficially, by climate-related stimuli (IPCC, 2007). Both exposure and sensitivity determine the potential impact climate change stressors can have on a system. Generally, vulnerability is dynamic, innovative, and a relative measure hence does not quantify the damage itself in absolute terms (Downing *et al*., 2001; Piya *et al*., 2014). The proxy measures of each vulnerability components are valuing and aggregated to give an overall vulnerability score for each dynamic and specific system (Adger, 2006).

The bio-physical (end-point), socio-economic (starting point), and the integrated assessment are widely used approaches for vulnerability assessment to climate change and variability (Füssel, 2007). IPCC (2000) defines vulnerability as the end-point impact on the system after hazard encounters. This vulnerability assessment approach disregarding the human adaptive capacity and structural factors to moderate climate change hazards (Madu, 2012). However, IPCC (2001) defines vulnerability as the starting point that exists within a system before a hazard is encountered dedicated to adaptive capacity. This approach mainly focused on the difference in the availability of resources depressing the physical environment as a static environment. IPCC (2012) considered vulnerability as the effect of diverse socio-economic, political, and environmental conditions. Hence, the integrated assessment approach systematically linked both approaches widely applied to assess systems' vulnerability to climate change (Deressa *et al,* 2009; Antwi-Agyei *et al.*, 2013).

Moreover, there is no universally accepted measurement of vulnerability methods due to the contested meaning and latent nature of the constructs (Downing *et al*., 2001; Adger, 2006). The common measurements to construct a vulnerability index is either assuming all the indicators having equal weight or assigning different weights for all indicators to control subjectivity (Eakin *et al*., 2009). This method includes choosing indicators and normalized to bring the values of the indicators within the comparable range (Antwi-Agyei *et al.*, 2013; Adu *et al*., 2018). This method tends to overestimate some less relevant indices while underestimating the relevant ones.

Weighting based on expert judgment is another approach though it leads to subjectivity and disagreement among the experts themselves (Zickfeld *et al.,* 2007). The fussy set approach involves both vulnerable and non-vulnerable households (Oyekele *et al*., 2004). The main drawbacks of the fussy method are unable to consider the effects of the adaptive capacity of the household and lack of dynamism over time. Generally, the indicator approach is limited by substantial subjectivity in the selection of variables and their relative weights, availability of data at various scales, and validating the different metrics (Luers *et al*, 2003).

Assigning different weights by principal component analysis (PCA) statistically is a remedial solution to overcome the limitations of the indicator method (Filmer and Pritchett, 2001). Therefore, assigning different weights using a multivariate statistical technique known as the PCA method is outweigh the former indicator method (Opiyo *et al.,* 2014). However, the vulnerability index developed using this method is neither a threshold nor an absolute value rather only a relative measure compared to other households (Notenbaert *et al.*, 2013).

In developing countries, rural institutional arrangements have an important function to maintain income and consumption fluctuation caused by idiosyncratic and covariant risks (Holzmann *et al*., 2003). Institutions are the rules of the game in society and humanly devised constraints that shape human interaction (North, 1990). Risk coping or risk management strategies through institutional arrangements categorized under informal, market-based, and public keeping the relative strengths and weaknesses (Holzmann *et al*., 2003; Lpízar, 2007). Determining the nature of interplay among these different institutional arrangements is essential for policymakers to implement comprehensive institutional reform for better social welfare (Koroso *et al.,* 2019). Moreover, understanding the interrelation between these rural institutional arrangements is very crucial to overcome the negative impact of climate-related shocks instead depend on a single institutional arrangement coping strategies (Uphoff and Buck, 2006).

Rural households use various risk coping mechanisms to deal with the impacts of climate-related and socio-political stresses. However, their risk coping strategies are varied by locations, preferences, objectives, financial and technological issues (Trærup and Mertz, 2011). The range of risk coping strategies households opted for is not similar for all indeed it varies based on their characteristics (Wood, 2003). The risk coping strategies among the Ethiopian pastoralists are highly gendered wise implies that women and men respond to risk in different ways (Getachew *et al.*, 2008).

## 1.8. General conceptual framework underpinnings

It is very difficult to develop a single universally accepted vulnerability assessment approach to conceptualize and measure the concept (Pearson and Langridge, 2008). This is more complicated since vulnerability assessment involves socio-economic, institutional, political, and biophysical systems (Krishnamurthy, 2014). IPCC Second Assessment Report (IPCC, 2000) defines vulnerability as the end-point impact on the system after hazard encounters. However, O'Brien *et al*. (2004) defend measuring vulnerability as an endpoint repressed the fundamental cause's leads to the adverse outcome. IPCC (2001) measures vulnerability as the starting point before a hazard is encountered focused on adaptive capacity. However, good vulnerability assessments need to integrate both these approaches (Füssel, 2007). Therefore, recently the majority of studies have motivated the human-environment system that causes hazards and their capacity to respond.

Füssel and Klein (2006) developed a broad conceptual framework for vulnerability assessments that involves four phases. First, impact assessment is developed based on scenarios of future climate change to investigate human-induced climate impacts. The second stage refers to first-generation assessment based on the first stage but considering non-climate factors and adaptation measures to address shocks. The third stage is called second-generation assessment which mainly emphasizes on adaptation measures. The adaptation policy assessments attention policy-makers to including risk reduction tasks. Unlike, the last two stages, Adger (2006) analyzed vulnerability that encompasses risks and institutional dimensions to determine the various scales through which vulnerability manifested. Moreover, Brooks (2003) introduces a conceptual framework to explain the relationships between vulnerability, adaptation, and risk to climate variability and dynamism in human interactions. Moser and Ekstrom (2010) developed a model that reveals successful adaptation embraces three main process steps: the first perception about hazards encountered then decide whether to adopt or not among the alternatives strategies and lastly implement the decided adaptation measures.

Vulnerability assessment should focus on the system being stressed such as food security instead of an assessment of a particular geographical area (Luers *et al*., 2003). Consistent with this notion, Füssel (2007) suggested that a full vulnerability should encompass four interrelated dimensions to describe the conceptual framework of the vulnerable situation correctly. First, the system potentially threatens by a hazard such as a human-environment or a population group. Turner *et al.* (2003) provide a vulnerability framework to measure the human-environment system to verify the application of the first vulnerability dimension. Second, the attribute(s) of concern the vulnerable system that is/are threatened by exposure to hazard such as livelihood outcomes. Third, internal or external hazards that can negatively affect the attribute of concern, such as adverse climate change and variability finally temporal reference used for a time of interest involved the present or future time. Moreover, the vulnerability assessment framework comprises adaptive capacity that includes non-climatic factors such as demographic, economic, political, and technological factors in addition to sensitivity and exposure factors (Füssel and Klein, 2006).

A livelihood is called sustained when it absorb risks and recover from adverse shocks while maintaining the original functions. Vulnerability to food insecurity and vulnerability to poverty estimated using the vulnerability as expected poverty approach and similar estimation procedures (Chaudhuri, 2003; Capaldo *et al.*, 2010). Vulnerability to food insecurity is a dynamic concept influence by the cumulative events over time (Ericksen, 2008). Diamond (1965) was among the pioneers who made an overlapping generation model that contains current and future food consumption behavior of households keeping the existing economic interactions. Following this model, Løvendala and Knowles (2005) argued that households' present food security status determined by yesterday's outcome and influences tomorrow's status. They were building up a conceptual framework involved household expected food security status entails the present ($t_0$) and the future ($t_1$) lifetime periods. Present results are perceived to households and policymakers how the food security status but both have not enough knowledge about future welfare outcomes. Because between these two time periods ($t_0$- $t_1$) there are several unstipulated factors like shocks and trends that will determine future food security influencing by households' risk coping strategies.

Risk coping strategies employed at the household level influence the timing and intensity of the vulnerability. The forward-looking dynamic model in this study suggested that future food security status can be determined based on the present household's food security status and the various risks and coping strategies. Risks can be idiosyncratic (uncorrelated) or spatially covariant (correlated) among people over time (Dercon, 2002). The World Bank's social risk management identified three institutional arrangements to address climate or non-climatic shocks (Holzmann and Jørgensen, 2001). This conceptual framework instigates by examining the various risk coping mechanisms that help either the vulnerable household's remained less vulnerable or further exposed (Anderson, 2003). Idiosyncratic risk is insurable through informal and/or market-based arrangements (Meinzen *et al.*, 2012). Contrary, spatially covariant risk is overwhelming the capacity of informal arrangements due to supply-constrained hence demand the application of public arrangement strategy.

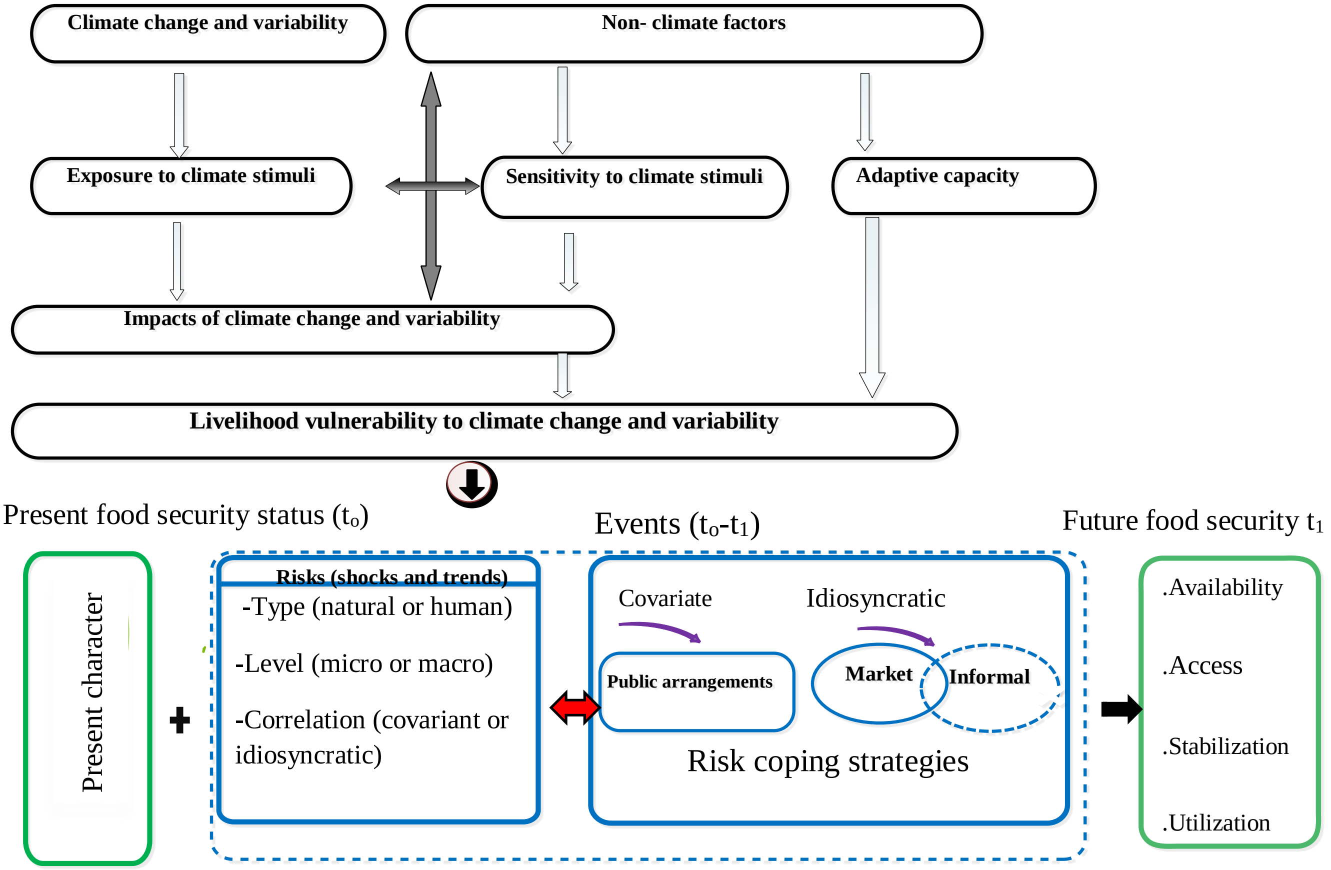


Figure 1.2 Conceptual framework of the study

Source: Own construction based on Füssel and Klein (2006); IPCC (2012); Løvendala and Knowles (2005); Balgah (2015)

## 1.9. General methodological approaches

### 1.9.1. Choice of methods

Scientific research should encompass and combine the research approach, design, and methods (Creswell, 2017). Research approaches are plans and procedures that involve methods of data collection, analysis, and interpretation (Creswell, 2017). The research approach encompasses quantitative, qualitative, and mixed methods taking into account their unique features. In quantitative research, the researcher uses a deductive approach as a framework to address the problem under consideration.

Whereas the philosophical epistemology paradigm (the study of knowledge) is based on a positivist approach attributed to the natural sciences and the ontology (i.e., nature of reality) is based on objective facts alike in social science research guide. Qualitative researchers are constructive from bottom-up by organizing the data into increasing units of information based on inductive orientation and interpretation epistemology. A mixed-method is the third research paradigm integrated both quantitative and qualitative approaches within a single study (Hadi *et al.*, 2013). Therefore, this study employed a mixed approach to provide a more complete understanding of the research problem than either approach alone.

### 1.9.2. Types and sources of data

The primary data was gathered through a household survey questionnaires, focus group discussion, key informant interviews, and field observation. Secondary data was collected by reviewing various sources of government documents. Specifically, data related to socioeconomic, demographic, and political-administrative setups were obtained from Hawzen and Irob Plan and Finance Office and Agriculture and Natural Resource Office. These sources include both published and unpublished documents.

### 1.9.3. Methods of data collection

**Household survey questionnaire**

A cross-sectional household survey was carryout involving all the necessary primary data consistent with the stated study objectives produced using a structured survey questionnaire included both open-ended and closed-ended types of questions. The structured questionnaire was pretested and administered at the household level to explore the research objectives of the study. Before the start of the study, the enumerators were given field training about the study objectives. The primary data collection was done between February and March 2018 administered by trained enumerators who speak the local language and supervised by local agricultural extension agents in the study Districts. The farm household survey includes questions on household characteristics, farmers' perception of climate change trends, climate change adaptation strategies, food consumption level, and climate-related risk coping strategies. The primary data collected from the household survey was presented in (*Annex 1.1*).

**Focus group discussions (FGD):** household heads for FGD were nominated based on their age, gender, and have a better knowledge of the study area. Each of the FGD composed of 8-10 people for each *Kebele* and a total of four FGD were held. Checklists were prepared in line with the major objectives of the study to produce the required information from the discussants. The presented open-ended questions were analyzed in a descriptive method (*Annex 1.2*).

**Key informant interview:** Key informant interview was conducted with each *Kebele* coordinator agronomy experts that have had a better knowledge, experiences, and observations regarding climate variability and extremes, adaptation strategies, and the common staple food households' consumed in the study area. For this study, a total of 8 key informant interviews were conducted from the four Kebeles (*Annex 1.3).*

**Field observation:** It is essential to generate information that could not be measured precisely using common data collection techniques. Accordingly, simple field observation on households' access and distributions of natural assets, implemented adaptation strategy measures, and the distribution of local infrastructure was made and supplement with other data sources.

**Secondary data:** annual rainfall and temperature data were used based on a 4 km by 4 km gridded data set over the period between 1983 and 2015/6. The gridded dataset merging including station gauge data from the National Meteorology Agency of Ethiopian (NMAE) and satellite rainfall and temperature estimations from the European Organization for the Exploitation of Meteorological Satellites and the US National Aeronautics and Space Administration. Finally, the Satellite rainfall estimates combined with stations gauge data by National Meteorological Services Agency together with its international partners.

### 1.9.4. Sampling design

A multi-stage sampling method was used to select sampled rural farm households in both Districts. In the first stage, Hawzen and Irob Districts were selected using a purposive sampling method from the seven rural districts that exist in the Eastern zone, Tigray region. These Districts were selected because of their high exposure to climate-related risks, comprise diverse ecological zones, and socio-economic conditions. In the second stage, two Kebeles (the smallest administrative unit below Districts) were selected from each district using a stratified sampling method. Selam and Alitena Kebeles categorized under midland climate conditions while Degamba and Hareze-Sebata are from highland agro-ecological zones. 1856 and 1395 household heads from Selam and Degamba Kebeles from Hawzen while 1607 and 355 household heads from Alitena and Hareze-Sebata in Irob were lived in 2016 respectively. In the third and last stage, 208 and 150 households were selected from each Districts proportional to the total number of farm household heads using a simple random sampling method.

Table 1.1 Summary of sampled households

| Districts | *Kebele* | AEZ | Population | Household head | Selected HH |
|---|---|---|---|---|---|
| Hawzen | Degamba | Highland | 5,319 | 1,395 | 88 |
| | Selam | Midland | 8,287 | 1,856 | 120 |
| Irob | Alitena | Midland | 7,141 | 1,607 | 105 |
| | Hareze-Sebat | Highland | 3,180 | 355 | 45 |
| | Total | | 24,960 | 5,009 | 358 |

The total sample size from each *Kebele* computed using the following standard mathematical formula (Yamane, 1967):

$$n = \frac{N}{1+ N(e^2)}$$

Where:

N = total population of the sample *kebele*

$n$ = sample size to be computed

$e^2$ = acceptable error (level of precision), which is assigned a value of 5 percent (0.05)

1= constant

The calculated sample size distributed to each *kebele* proportional to its size to make equal representation.

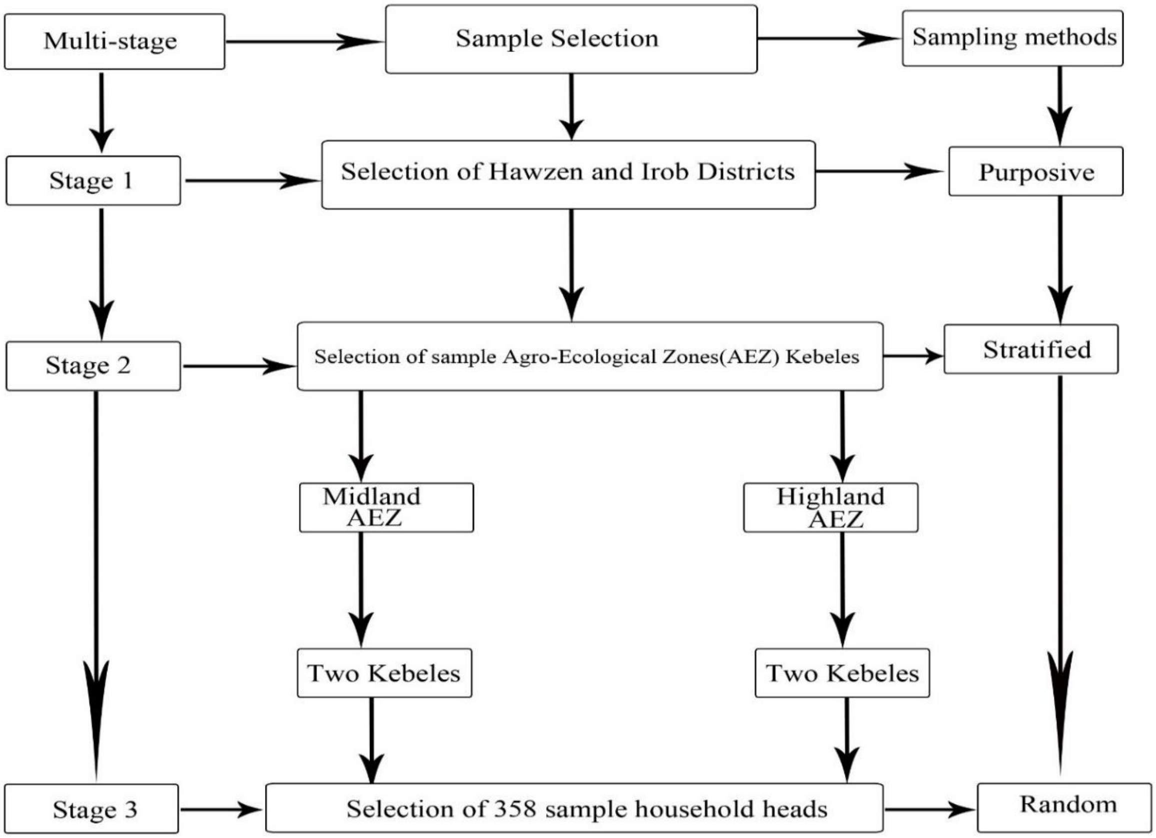


Figure 1.3 Sampling strategy: stages, sampling methods, and sample size

### 1.9.5. Methods of data analysis

The triangulation method uses multiple methods and theoretical constructs to advance the validity of the study. Especially, triangulation is very important in mixed-method by mixing qualitative and quantitative data. Triangulation permits the researcher to uses a variety of data sources and analyses to write up the study. This study involves a range of qualitative data instruments including FGD, Key informant interview, and field observation to describe the study area along with information obtained from the secondary data sources.

The quantitative data analysis techniques include descriptive statistics, MKT, cluster analysis, indexed approach, and econometric models. The descriptive method applied to compute farm household's perception, livelihood capital, and rainfall and temperature variability. Furthermore, basic inferential statistics were used to test whether there is a statistically significant difference between the two Districts in terms of farmer's perception, capital endowment, household vulnerability, climate variability, and adaptation measures. Mann Kendall's method is used to identify the direction and magnitude of significant trends of rainfall and temperature during the period of analysis. The K-Means cluster analysis method is used to classify households into three vulnerability categorize. Moreover, the HVI method employed to assess households' vulnerability to climate change and variability based on IPCC vulnerability definition. The Foster-Greer-Thorbecke (FGT) method was used to calculate the food insecurity indexes.

A two-step Heckman Prohibit selection model is used to examine the determinant factors that influence farmers' perception and adaptation strategies to deal with their perceived impacts. To analyze the household's mean and variance of food consumption expenditure, the three-step Feasible Generalized Least Squares (FGLS) method was employed which is suggested by Amemiya (1977). Moreover, the Multivariate probit (MVP) regression model was utilized to estimate the factors that influence to choose households the various risk coping strategies. Detailed specifications of the analytical tools and the econometric models are provided in the respective chapters. Different software packages like STATA®14, XLSTAT 2018, Arc-GIS (10.2), and Spreadsheet were employed to analyze, summarize, and discuss the quantitative data.

## 1.10. Organization of the dissertation

This Ph.D. dissertation is organized into six chapters as follows: Chapter one presents the general background of the study, problem statement, objective; research questions; scope and delimitation of the study, and study area description. Moreover, it involves theories and concepts, general conceptual framework, and methodological approach the study mainly rely upon it. Chapter two highlights the first two research questions that underscore the fundamental portion of this work. This begins by exploring farm households' perceptions about rainfall and temperature *vis-à-vis* the long term meteorological data.

Further, analyze the determinants of farm household's perception and adaptation measures to climate change and variability. This includes examining farmers' perception parameters, compute the coefficient of variation (CV), standardized rainfall anomaly (SRA), and Mann-Kendall and Sen's slope estimator to examine the spatiotemporal trends of temperature and rainfall. Moreover, estimate the Hackman Probit model that fits a maximum-likelihood probit model with sample selection to analyze the factors that determine farmers' perception and adaptation strategies to the perceived decline in rainfall.

Chapter three provides a brief description of the second research question. This chapter involves measuring and clustering of household livelihood vulnerability to climate change and variability employing the integrated vulnerability assessment approach and K-means clustering algorithm. Addressing this research question includes constructing HVI using the PCA method driving from the main components of vulnerability.

Chapter four concerns an overview of the third research question and sets out with the description of the conceptual and analytical food insecurity vulnerability thereby decomposing and estimating household vulnerability to food insecurity. Specifically, this chapter examining the determinants of households' food insecurity vulnerability to climate change using vulnerability as an expected poverty approach after defining the food poverty line.

Chapter five focused on the last fourth research questions. It thoroughly examines the major shocks rural households experienced over the last ten years that expected to have a serious effect on food security status. Besides this chapter examined the factors affecting the household's decision to choose multiple institutional arrangements as a risk coping strategy to deal with climate change impacts. Besides, it identified the role of intra-household risk-coping strategy to share risk during food consumption fluctuation. Lastly, chapter six presents a conclusion, recommendations, contribution of the study, and providing a suggestion for future research.

# Chapter Two

## 2. Farmers' perceptions and adaptation to changing climate

### *Abstract*

*Understanding farmers' perceptual is vital in order to encourage farm adaptation.* Because, *farmers' perception of climate change influences their adaptation measures and preferences. The study aims to examine farmers' perceptions of climate change trends and its influence on adaptation measures. Primary data were collected from 358 randomly selected farm household heads in Hawzen and Irob districts complemented with annual rainfall and temperature data from 1983 to 2015. The non-parametric Sen's slope estimator and modified Mann-Kendall test have been used to identify the existence of slope magnitude and trends in temperature and rainfall. Moreover, the Heckman probit selection model was used to examine the two-step process of adaptation strategies to climate change and variability. The result showed that 95 percent of farmers' perceived annual rainfall was decreased while 89 percent notice an increased average temperature over the last fifteen years in Hawzen and Irob Districts, respectively. Annual rainfall was highly variable and decreased insignificantly by about 32 and 121 mm while annual mean temperature increased significantly* ($P<0.01$) *by* $0.4^0C$ *and* $0.39^0C$ *per decade, respectively. The results of the Heckman probit model indicated that the factors that significantly affected farmers' perceptions were access to agricultural extension services, weather information, and training, membership in social networks, and negative rainfall trend. Moreover, water and soil adaptation measures were significantly influenced by age, household size, agricultural extension services, off-farm activities, weather information, and mean rainfall trend. Policy-makers should make an enabling environment to promote adaptation by increasing labor force participation, agricultural extension services, off-farm activities, and access to weather information. Moreover, farmers' level of climate change understanding and adaptation decision could be fostering through human development using the community-based organizations.*

***Keywords****:* Rainfall, temperature, perception, adaptation, Mann-Kendall test, Heckman Probit

## 2.1. Introduction

An increase in intensity and frequency of extreme weather events and climate variability has raised broad concerns over global climatic changes since it harms human livelihood activities and strategies (Rahman and Begum, 2013; Chen *et al.,* 2017). The interplay between rainfall and temperature is the most indispensable hydrological and climatological information often used to characterize climate change and variability (IPCC, 2007; Sharma *et al*, 2016). Global summer rainfall had an increasing trend during 1901-1955 but a decreasing trend since the 1950s (Zhang and Zhou, 2011). The GMST increased by about $0.89^0$C during 1901-2012 because of human-induced greenhouse gas concentrations (IPCC, 2013). As a result, globally, the average temperature is estimated to increase between $1.48^0$C and $5.88^0$C by 2100 which leads to frequent extreme weather events and risks (IPCC, 2001). Rainfall variability and extreme climate impacts account for a significant share of agricultural production decline (FAO, 2008). Globally, economic losses in agricultural production caused by climate change accounts for about 5 USD billion per year (Stevanović *et al.*, 2016).

Africa has been identified as highly vulnerable to climate change and variability (IPCC, 2017). In SSA, warming is expected to be higher than the global average, and in some parts of the region, rainfall will decline (IPCC, 2007). Africa is likely to experience extreme drying in most subtropical regions with slight increases in rainfall in the tropics (simulation *et al*., 2013). This is a major challenge for the 95 percent rain-fed agricultural production in SSA unless effective adaptation measures have been implemented (Asare-Nuamah and Botchway, 2019; Wiebe *et al.*, 2019). The climate change impacts in Africa is exacerbated due to low adaptive capacity (UNEP, 2011).

Low adaptive capacity in the agriculture sector worsens climate change vulnerability in Africa (FAO, 2012). Azadi *et al*. (2019) suggested that appropriate adaptation measures are vital to address climate change impacts. Many empirical evidence underlined that adaptation decision is closely linked to farmers' perceptions about climate change impacts (Fadina and Barjolle, 2018; Hasibuan *et al*., 2019). However, perceptions of climate change impact are not extensively studied in Africa and varies greatly from community to community (Steynor and Pasquini, 2019; Steynor *et al.,* 2020).

Farm households in rural Ethiopia primarily depend on low-productivity rain-fed agriculture that causes socio-economic development challenges and food insecurity (Cheung *et al.*, 2008). FAO (2010) underlined that a severe decline of the main rainy season is the cause of recurrent food shortages in Ethiopia. Moreover, Ethiopia's GDP growth is strongly correlated with rainfall and negatively affected by rainfall variability (World Bank, 2006; Seid, 2012). Climate change has affected the agricultural sector in Ethiopia due to the increasing temperature trend observed throughout the country (Serur, 2020). Thus, effective adaptation measures in the agriculture sector are necessary to protect the livelihoods of poor people (Kumamoto and Mills, 2012).

Several studies have been made to investigate the spatiotemporal variability of rainfall and temperature in Ethiopia (Bewket and Conway, 2007; Rosell, 2011; Wagesho *et al.*, 2013; Kiros *et al.*, 2016; Asfaw *et al.*,2018). Nevertheless, their results were inconclusive due to differences in the period and unit of analysis carried out at regional, basin, and national levels. Ahmad *et al.* (2017) suggested that for efficient and effective decision-making trend analysis at a lower scale time-series data is more preferred. Because, understanding the spatiotemporal variation in temperature and rainfall changes over large areas are confused due to the existence of non-uniformity (Akinremi *et al.*, 2000).

Regarding the perception of smallholder farmers about climate change and actual meteorological data analysis, there was mixed evidence in Ethiopia. Ayal and Leal Filho (2017) revealed that farmers' perceptions of increasing temperature were analogous with meteorological data but perceptions of decreasing rainfall trends were incongruent with meteorological data in Northwest highland of Ethiopia. Moreover, Hundera *et al.* (2019) found that farmers' perception of increasing temperature was cognate with meteorological data but the perception of decreasing rainfall was not in line with meteorological data analysis in Adama District, central rift valley of Ethiopia. In contrast to this finding, Moroda *et al.* (2018); Ayal *et al.* (2018) concluded that the majority of farmers' perceptions about temperature and rainfall changes were cognate with meteorological data in East Shewa and Borana zone Ethiopia, respectively. Limantol *et al.* (2016) revealed that farmers' perceptions of increased temperature were tallied with actual climate data, but their decreased perception in rainfall was contrasting with rainfall climatic data in Ghana. Hence, there is a gap between local farmer perceptions and actual climate data, though, policies are framed using national and/or regional scenarios by overlooking the local context (Asare and

Botchway, 2019). However, the national climate change modeling system not necessarily coincide with local farmers' perceptions (Vignola *et al*., 2013).

Understanding the relationship between farmer's perception and actual climate information is useful to develop adaptation measures under poor weather information dissemination systems (Luís *et al*., 2018). Because climate change perception influences farmers' choice of adaptation decision (Abid *et al.,* 2015; Fadina and Barjolle, 2018). Moreover, farmers' perception of climate change facilities to implement action against its adverse impacts (Gbetibouo, 2009). However, adequate scientific climate change information is not always provided to farmers in most developing countries (Weber, 2010). Household's perception of rainfall is an idiosyncratic manifestation of their experience and environmental aspects (Meze, 2004). Moreover, Deressa *et al*. (2009) emphasized that farmers' perceptions of climate change do not rely on actual climate change rather it depends on their socio-economic condition and past farming experiences. Therefore, farmers' perception of climate change is a prerequisite for adaptation decisions (Tripathi and Mishra, 2017; Alam *et al*., 2017). Asare-Nuamah and Botchway (2019) suggested that farmers must perceive climate change before adapting to climate change impacts.

However, few studies have been devoted to understanding the influence of farmers' perceptions on adaptation measures to reduce the negative climate change impacts. Therefore, integrating farmers' perception of climate change with local meteorology data has received broad attention to facilitate adaptation strategies (IPCC, 2014). As a result, this present study examines the relationship between farmers' perceptions and long term meteorological data. Further, investigate the factors that influence farmers' perception and adaptation strategies to climate change and variability.

## 2.2. Methodology

### 2.2.1. Data sources

The data for this study were collected from both primary and secondary sources. The primary the source is a cross-sectional survey data collected from randomly selected 358 rural farm households. Moreover, the secondary data involves annual temperature and rainfall ranges from 1983-2015.

### 2.2.2. Methods of data analysis

Tests for the detection of significant trends in climatology grouped as parametric and non-parametric methods (Gocic and Trajkovic, 2013). Coefficient of variation (CV) and standardized rainfall anomaly (SRA) from parametric and Mann-Kendall test (MKT) and Sen's slope estimator as non-parametric methods were used to study the temporal trends of temperature and rainfall.

The CV is a widely used technique to analyze inter-annual variability of rainfall computed as the ratio of the standard deviation to mean value over the given period (Ayal and Leal Filho, 2018; Alemayehu and Bewket, 2017). A rainfall amount with CV of less than 0.20 is less variable, between 0.20 and 0.30 is moderately variable, and greater than 0.30 is highly variable (National Meteorological Services Agency (NMSA, 1996). Moreover, SRA is calculated as the difference between long term mean annual rainfall and observed annual rainfall to the ratio of standard deviation assuming that the observations are normally distributed (Viste *et al.*, 2013). SRA helps to characterize the pattern of rainfall fluctuation comprises over time and severity of meteorological droughts (Alemayehu and Bewket, 2017; Ayanlade *et al.*, 2018). A negative anomaly of rainfall at 25 percent and 50 percent refers to dry and very dry conditions, respectively (NMSA, 1996).

### 2.2.3. Mann-Kendall trend test

The basic premise of the MKT test, offered by (Mann, 1945; Kendall, 1955) is a test of random series ordered against non-random ordering of a series in time (Hamed, 2009). The null hypothesis $H_0$ of the MKT assumes that the data are independent and randomly ordered, *i.e.*, there is no significant trend against the alternative hypothesis which assumes there is a trend (Önöz and Bayazit, 2003). Mann Kendall's method is useful to identify the direction and magnitude of significant trends due to its low sensitivity to abrupt breaks and missing values are permitted (McBean and Motiee, 2008). This method is not significantly touched by single data errors or outliers (Hamed, 2009). Moreover, the data should be detached from any serially independent that cause unreliable results. In case any serial autocorrelation exists, the Modified Mann-Kendall (MMK) test was used to get rid of the impact of autocorrelation (Hamed and Rao, 1998). Hence, before embarking on a monotonic trend test, lag 1 autocorrelation for all the time series was determined using the autocorrelation function. The test has been used by many researchers using the same applications (Hamed and Rao, 1998; Hamed, 2009; Bari *et al.*, 2016).

The MKT test method primarily involves the standardized test statistic $Z$ and Sen's slope $\beta$ parameters. The MKT statistic computes the difference between the later measured value and all early measured values of a time series of interest over time. If a data value from a later time is higher than a data value from an earlier period, the statistic $S$ is incremented by 1. On the other hand, if the data value from a later time is lower than a data value sampled earlier, S is decremented by 1. The net result of all such increments and decrements yields the final value of S. The Mann-Kendall test statistic 'S' is calculated based on Mann (1945), Kendall (1975) and Yue *et al.* (2002) using the formula below:

$$S = \sum_{k=1}^{n-1} \sum_{j=i+1}^{n} \mathrm{sgn}\,(x_j - x_i) \qquad (2.1)$$

Where $n$ denotes the length of a dataset, $x_j$ and $x_i$ are the sequential data values at times $j$ and $i$ and $(j > i)$.

$$\mathrm{sgn}\,(X_j - X_i) = \begin{cases} +1 & \text{if}(x_j - x_i) > 0 \\ 0 & \text{if}(x_j - x_i) = 0 \\ -1 & \text{if}(x_j - x_i) < 0 \end{cases} \qquad (2.2)$$

Where $sgn$ denotes the sign function that takes on the values 1, 0,-1if $x_j > x_i$, $x_j = x_i$ or $x_j < x_i$, respectively. Positive S values indicate an increasing (upward) trend, and negative values of S reveal a decreasing (downward) trend in the time series data.

For samples,$n \geq 10$, S statistics is an approximately normal distribution with mean and variance as follows (Helsel and Hirsch, 2002):

$$E(S) = 0 \qquad (2.3)$$

$$\sigma^2 = \frac{1}{18}[n(n-1)(2n+5)] \qquad (2.4)$$

If a tie is present in the data, then the variance ($\sigma^2$) statistic is given as:

$$\sigma^2 = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i - 1)(2ti + 5)\right] \qquad (2.5)$$

Where m the number of tied groups and $t_i$ is the number of observations in the $i^{th}$ group. The standardized MK test statistic $Z_{MK}$ which follows the standard normal distribution with a mean of zero and variance of one is as follows:

$$Z_{MK} = \begin{cases} \frac{s-1}{\sqrt{\delta^2}} & \text{if } s > 0, \\ 0 & \text{if } \quad s = 0, \\ \frac{s+1}{\sqrt{\delta^2}} & \text{if } s < 0. \end{cases} \tag{2.6}$$

A positive (negative) value of S indicates an increasing (decreasing) trend for the period respectively. The trend is insignificant if $Z_{mk}$ is less than the standard normal variate $Z\alpha/2$ where α% is the significance level. Testing trends are done at the specific α significance level. When $|Z_s|>Z_{1-\alpha/2}$ , the null hypothesis is rejected and a significant trend exists in the time series.

The parameter $\beta$ (the trend magnitude), indicating the variation rate within the time series is given by Sen's Slope estimation test computes both the slope and intercept (Theil, 1950; Sen, 1968). A positive value of β indicates an 'upward trend' (increasing values with time), while a negative value of β indicates a 'downward trend'. In general, the slope between any two values of a time series *x* can be estimated from:

$$\beta = Median \left[\frac{X_{j-} X_k}{j - k}\right] \tag{2.7}$$

Where, $X_j$ and k are data values at times j and k, (j>k) respectively.

Tau (Kendall, 1938, 1948) measures the strength of the monotonic relationship between x and y. Therefore, Kendall's tau correlation coefficient is given by:

$$\tau = \frac{S}{n(n-1)/2} \tag{2.8}$$

A positive value of τ indicates an increasing trend and vice versa. The summation of the Mann-Kendall test statistic (S) indicates how strong the trend in temperature and precipitation is and whether it is increasing or decreasing.

### 2.2.4. Heckman probit selection model specification

According to Heckman (1976) when a farmer's decision process about the acceptance of new technology needs to postulate a two-step process Heckman sample selection model is suited to overcome the problem of sample selection bias generated during the decision making processes. Adaptation to climate change is a two-step process that involves perceiving a climate is changing and then responding to the change through the adoption of various adaptation strategies (Deressa *et al.,* 2011; Asrat and Simane, 2018). Heckman models are established on the simultaneous estimation of two multiple regression models, an outcome equation and a selection equation (Barnighausen *et al*., 2011).

The present study utilized the Heckman probit selection model to examine the determinant factors that influence farmers' perception and adaptation strategies to deal with their perceived impacts. The first stage of the model (the selection model) contemplates whether a farmer perceived a change in the climate, and the second stage of the model (outcome model) explores whether the farmer adapted to climate change conditional on the first stage.

In most cases, the outcome model is similar to any other multiple regression model and continuous, binary, or other types of dependent variables used as dependent variables (Bushway *et al.,* 2007). The two-step Heckman probit model begins with the specification of the outcome equation, a probit model specified as follows:

$$y_j{}^* = x_j\beta + u_{1j} \qquad (2.9)$$

Where $y_j{}^*$represents the unobserved latent variable that determines the propensity of farmers to adopt CC strategies$j$, and $y_j{}^*$depends on a k-vector of observed independent variables $x_j$ which hypothesized to affect adaptation, $\beta$ is the parameter estimate, and $u_{1j}$ denotes the unobserved random error term. Actual adaptation to climate change $y_j{}^*$is either zero (0) or positive (1), depending on whether $y_j{}^*$ is greater than or below zero. The zero observations lead to biased results when using ordinary least squares to examine households' adaptation strategies (Green, 2012).

The dependent variable for the selection equations must be binary, as the decision being modeled an individual's to perceive climate change or not. The basic premise of the Heckman sample selection approach is the assumption of bivariate normality functional forms that claims the use of the probit model. Therefore, the selection model is specified using a probit regression model and estimated utilizing maximum likelihood as follows:

$$y_j^{probit} = (y^* > 0) \qquad (2.10)$$

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

$$y_j^{select} = \left(z_j\delta + u_{2j} > 0\right) \qquad (2.11)$$

$$u_1 \backsim N(0,1)$$

$$u_2 \backsim N(0,1)$$

$$corr(u_1, u_2) = \rho$$

Where $y_j^{select}$ is whether a farmer has perceived climate change or not, $z$ is an $m$ vector of explanatory variables, which include different factors hypothesized to affect perception; δ is the parameter estimate, $u_{2j}$ is an error term and $u_1$ and $u_2$ are error terms, which are normally distributed with mean zero and variance one. Thus, the first stage of Heckman's two-step model is the selection model (equation 2.11), which denotes the farmer's perception of climate change. The second step is the outcome model (equation 2.9), which denotes whether the farmer adapted to climate change, and is conditional upon whether this has been perceived. If the error terms from the selection and the outcome equations are correlated or $\rho \neq 0$, standard probit techniques applied to equation (2.9) produce biased results.

### 2.2.5. Model variables description

The dependent variable in the empirical estimation is whether a farmer adopted water and soil conservation (WSC) adaptation strategy or not following the perception of climate change impacts. The choice of the independent variables that determine farmers' perceptions and adaptation strategy is a vector of household socio-demographic, economic, institutional, and mean annual rainfall and temperature selected based on the availability of data and literature (Deressa *et al.* 2009; Gbetibouo, 2009; Limantol *et al.*, 2016; Ayal and Leal Filho, 2017; Moroda *et al.*,2018). The result of the outcome model is crucial than the selection model in the two step estimation procedure (Deressa *et al.*, 2011). Hence, the variable description presented below is only for the outcome model.

Male-headed households use WSC adaptation measures more than female-headed households in rural Ethiopia since the female has poor access to climate information, agricultural training, and cultural barriers (Deressa *et al*., 2011; Bedeke *et al.*, 2019). Male and old age headed households positively influence adaptation measures in Ethiopia (Adimassu and Kessler, 2016). Alemayehu and Bewket (2017) found education was an important determinant of adaptation in the Amhara region, Ethiopia. In developing countries, large family size is helpful for labor-intensive adoption measures (Asfaw *et al.*, 2013). In contrast to this finding, Legesse *et al.* (2013) concluded that large family size had a significant negative influence on WSC adaptation measures in rural Ethiopia. This present study hypothesis a direct relationship between WSC adaptation strategy and family size.

Households with large livestock holding rely on animal manure fertilizers to retain soil fertility hence, decrease the adoption of the WSC adaptation strategy (Mulwa *et al., 2017).* Moreover, Deressa *et al*. (2011) found that livestock ownership is negatively influenced crop varieties and irrigation adaptation measures. Access to government agricultural extension services has important benefits to decided adaptation strategies (Glendenning, 2010). Furthermore, Atinkut and Mebrat (2016) confirmed that extension services had a significant positive influence on farmers' choice of adjustment to climate variability in rural Ethiopia.

Alemayehu and Bewket (2017) revealed that off-farm employment had a positive but insignificant influence on households' WSC adaptation strategy Amhara region, Ethiopia. Access to climate information promoted farmers' adaptation responses in rural Ethiopia (Bryan *et al*., 2013; Adimassu and Kessler, 2016). Drought and flood are among the major climate extreme events that caused low productivity and high soil degradation in Ethiopia (Deressa *et al*., 2011). Therefore, farmers exposed to frequent drought were adopted agroforestry adaptation strategies in the Nile Basin of Ethiopia (Teklewold *et al.*, 2019).

Large farm size increased the likelihood of using SWC measures in rural Ethiopia (Moroda *et al.* 2018; Bedeke *et al.*, 2019). Against this result, Alemayehu and Bewket (2017) indicated that farm size has an insignificant effect on adaptation measures. Good soil fertility decreased farmers' adaptation strategy because they receive more returns without major investment in SWC measures

(Shiferaw *et al.*, 2014). However, this present study hypothesis a direct relationship between WSC adaptation strategy and farm size.

Generally, institutions enhanced climate change adaptation measures by facilitating action being implemented at the local level (Agrawal, 2008, 2010). Long-distance from local market centers is a manifestation of limited information access to local weather conditions (Kaliba *et al.,* 2000). Bedeke *et al.* (2019) showed that the likelihood of adopting SWC practices positively related to market distance. In this study, the effects of climate change measured by annual rainfall and temperature trends (1983-2016) in each *Kebele*. Higher trends in rainfall and temperature increased the likelihood of an SWC adaptation measure in Malawi (Asfaw *et al*., 2013). Farmer's perception of climate change was influenced by the agro-ecological zone in Uganda (Okonya *et al.,* 2013). The lowland agro-ecological zone was more vulnerable to climate variability and change in Ethiopia (Dendir and Simane, 2019).

## 2.3. Result and Discussion

### 2.3.1. Sample household characteristics

Table 2.1 gives the summary statistics of social-demographic, economic, and local institutional environments of the sampled household heads. Consequently, of the surveyed households, 77 percent were male-headed households, with an aggregate mean age of about 52 years, implying that respondents were relatively elderly with long farming experiences. Household heads on average had 2.26 years of education that may impair their perception behavior and understanding capacity (Hisali *et al.,* 2011).

The self-reported subjective measurement of climate information indicated that 71 percent of household heads received access to weather information from various media outlets and rural institutions. Further, Table 2.1 exhibited ANOVA (Analysis of Variance), chi-square, and bivariate correlation tests. ANOVA Scheffe's and $\chi^2$-The tests were used to examine whether there was a difference in means of continuous and categorical variables between the two districts respectively. Hence, a statistically significant mean difference was found where (P<0.01) between Hawzen and Irob sample household groups.

Pearson's correlation test was also applied to assess the intensity and guidance of the linear relationship between access to climate information and households' characteristics (Dong et al., 2018). Climate information or access to weather forecast was positively correlated with training received at farmer training center (FTC) ($r = 0.22$, $P < 0.01$), and a number of social networks ($r = 0.22$, $P<0.01$) but negatively correlated with distance to the market ($r =-0.48$, $P < 0.01$). Households who have limited contacts with local farmer's institutions can get agricultural technology information from their family social networks (Gebreegziabher *et al.,* 2016; Wainaina *et al.,* 2016). But long-distance from local market centers is a manifestation of limited information access on local weather conditions (Kaliba *et al.*, 2000).

Furthermore, household age was negatively correlated with access to weather information ($r =-0.15$, $P<0.01$). Older farmers have limited social networks and poor interactions with rural institutions ultimately negatively influence access to climate information (Muema *et al.,* 2018). Moreover, Kirui *et al.* (2014) underlined that older farmers preferred indigenous knowledge over modern climate information services. Access to agricultural extension services (AES) positively correlated with access to climate information ($r =0.66$, $P<0.01$). Agricultural extension services have influenced farmers' decision to change their farming practices in response to climate change (Maddison, 2007). Farming households with poor contact with extension agents' services less likely to perceive the impact of climate change or would see it wrongly in developing countries (Bryan *et al.,* 2013). Generally, households' access to climate information was enriched through the provision of training at the FTC, access to agricultural extension services, and the number of social network households participated. Access to rainfall forecast information is helpful to farmers for better selection and timely growth of crops (Deressa *et al.,* 2009).

Table 2.1 Mean, standard deviations, and pairwise correlations (n=358)

| S/N Variables | Mean | SD | P-value | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.Sex of HH (% male) | 0.77 | 0.42 | 0.000 | | | | | | | | | |
| 2.Age of HH | 52.4 | 12.27 | 0.000 | $0.28^{a}$ | | | | | | | | |
| 3.Education of HH | 2.26 | 2.98 | 0.359 | $0.29^{a}$ | $-0.34^{a}$ | | | | | | | |
| 4.Access to AESs (% yes) | 0.62 | 0.48 | 0.000 | -0.08 | $-0.13^{b}$ | 0.07 | | | | | | |
| *5.Weather information(%yes)* | 0.71 | 0.45 | 0.000 | -0.14 | $-0.15^{a}$ | 0.04 | $0.66^{a}$ | | | | | |
| 6. HH own radio/ TV (%yes) | 0.40 | 0.49 | 0.196 | $0.11^{b}$ | -0.05 | $0.17^{a}$ | $0.14^{b}$ | 0.04 | | | | |
| 7. Access to FTC training | 0.28 | 0.45 | 0.000 | 0.01 | -0.08 | $0.13^{b}$ | $0.27^{a}$ | $0.22^{a}$ | $0.11^{b}$ | | | |
| 8. Number of off farm activities | 0.86 | 0.66 | 0.000 | $0.10^{b}$ | $-0.16^{a}$ | $0.12^{b}$ | $-0.21^{a}$ | -0.08 | 0.06 | -0.03 | | |
| 9.Distance to market (minute) | 52.48 | 69.87 | 0.000 | $0.13^{b}$ | $0.13^{a}$ | -0.08 | $-0.47^{a}$ | $-0.48^{a}$ | -0.01 | $-0.15^{a}$ | $0.16^{a}$ | |
| 10.Number of social networks | 1.41 | 1.53 | 0.000 | 0.02 | $-0.14^{a}$ | $0.22^{a}$ | $0.25^{a}$ | $0.22^{a}$ | $0.22^{a}$ | $0.26^{a}$ | -0.05 | $0.22^{a}$ |

[a] significance level at $P<0.01$; [b] $P< 0.05$; HH= household head, respectively

## 2.4. Adaptation and perception of climate change

In Ethiopia, 25 percent of the total land is degraded, hence to overcome this serious problem the government of Ethiopia has to introduce SWC adaptation measures since the mid-1970s (Sileshi *et al.,* 2019). This study found that 87.71percent of farmers were employed SWC planned adaptation strategy to ease the adverse effects of climate change and variability and increase crop productivity. Moreover, planting trees (84.64 percent), crop varieties (81percent), changing crop planting times (64.25percent), biological conservation (43.58percent), and irrigation (19 percent) were common adaptation measures to address climate change impacts, respectively. All these strategies do not necessarily use directly to reduce climate change impacts (Alam *et al.,* 2017).

Specifically, in Irob currently, 2 percent of the land is under cultivation of the total area due to severe land degradation and steeped land slope. Consequently, the average landholding size per household head estimated around 0.02 Hectare. Hence, farmers adopted different SWC practices including built bench terrace, soil bunds, and stone bunds based on the land use types to improve soil fertility and extensive farming. Sileshi *et al*. (2019) found that smallholder households' adaptation of these SWC components is interrelated in Eastern Ethiopia. SWC adaptation measures have several benefits, such as improved productivity, decreasing water erosion, and encouraging the formation of natural terraces in the future. Table 2.2 presented that about 85 percent of farmers in the study area perceived a change in climate from time to time in their localities that is a precondition for adaptation measures.

Table 2.2 Farmers' perceptions of climate change

| Perception | Hawzen | | Irob | | Total | | $\chi^2$-value |
|---|---|---|---|---|---|---|---|
| | N | Percent | N | Percent | N | percent | |
| Perceived | 178 | 85.58 | 126 | 84 | 304 | 84.92 | 0.169 |
| Not- perceived | 30 | 14.42 | 24 | 16 | 54 | 15.08 | |
| Total | 208 | 100 | 150 | 100 | 358 | 100 | |

Approximately, 84 percent and 93 percent of households in Hawzen and Irob districts adopted the SWC adaptation strategy as a planned adaptation strategy, respectively (Table 2.3). This variation in adaptation measures is statistically significant ( $\chi^2$ = 7.575, P< 0.01), showing the existence of a verified difference between the two districts. Effective, adaptation strategy is implemented at the local level rather than being a nationally imposed option (Eriksen and Lind, 2009).

Table 2.3 Soil and water conservation adaptation strategy decisions

| Adaptation decision | Hawzen | | Irob | | Total | | $\chi^2$ value |
|---|---|---|---|---|---|---|---|
| | N | Percent | N | Percent | N | percent | |
| WSC adaptors | 174 | 83.65 | 140 | 93.33 | 314 | 87.71 | 7.575*** |
| Non- adaptors | 34 | 16.35 | 10 | 6.67 | 44 | 12.29 | |
| Total | 208 | 100 | 150 | 100 | 358 | 100 | |

*** Significance level at P<0.01

## 2.5. Farmers' perception of rainfall and temperature variability

Table 2.2 presents farmers' perception of climate change and variability in terms of rainfall distribution, amounts, and increasing temperatures over the last fifteen years. Farmers had no wide difference in perception of climate change and undeniably majority of households perceived a notable change in rainfall and temperature. Out of the total farmers, 98.56 percent and 92 percent perceived a decrease in rainfall amount in Hawzen and Irob respectively. A significant difference was found ($\chi^2$ test, $P< 0.01$), indicating that households who had been in Hawzen were more likely to perceive a decrease in rainfall compared to those in Irob. Approximately, 40 percent and 20 percent of households believed that variability in onset and cessation time of rainfall is much in the last fifteen years, respectively (Table 2.4).

Furthermore, Table 2.4 showed that around 29 percent and 39 percent of households in Hawzen and Irob districts noted that the number of rainy days was decreased. Nonetheless, few households suggested that even when it rains the intensity of rainfall is increased. 5 percent of households from Hawzen observed abnormality in rainfall timing and distribution was increased. Further, almost 37 percent of households in Irob understood that the occurrence of drought frequency was increased, while only 2.4 percent viewed alike to this opinion in Hawzen. Around, 92 and 98 percent of households in Hawzen and Irob noticed rainfall patterns of last summer were stopped too early, respectively. Besides, around 25 percent of households in Hawzen witnessed rain during harvest time last year.

Moreover, 87 and 90 percent of households' felt that the temperature was increased in the last 15 years in Hawzen and Irob, respectively. The significant ($\chi^2$-test, $P<0.001$) showed that households who had been in Irob were more likely to perceive an increase in temperature compared to Hawzen. Furthermore, about 77 and 78 percent of households perceived an increase of hot days while 7 and 5 percent noted decreased the coldness of cold seasons respectively. Generally, the majority of farmers are aware of the presence of climate change and variability manifestations in their locality.

Farmers' self-reported climate perception is highly personal, site-specific, and influenced by several biophysical factors hence require to underpin by meteorological information (Niles and Mueller, 2016). Meteorological annual rainfall data analysis was congruous with farmers' perception of rainfall decreased in both districts (Table 2.4). This is consistent with studies in Ethiopia (Mengistu, 2011; Ayal *et al.*, 2018). Moreover, farmers' perceptions of an increased temperature were in harmony with the meteorological data (Table 2.8). The harmony between farmers' perception of an increasing temperature trend and meteorological records is also supported by previous works of (Legesse *et al.*, 2013; Ayal *et al.*, 2018; Moroda *et al.*, 2018).

Table 2.4: Farmers' perception of rainfall, temperature and weather extremes (n=358)

| Perceptions of climate parameters | Hawzen percent[¥] | Irob percent | $\chi^2$-value |
|---|---|---|---|
| Rainfall decrease in the last 15 years: | | | 13.32*** |
| Yes | 98.56 | 92.00 | |
| No | - | 4.67 | |
| Stayed the same | 0.96 | 3.33 | |
| Don't know | 0.48 | - | |
| Local perceptions of rainfall variability: | | | 120.78*** |
| Variability in onset and cessation time of the rainy season | 39.42 | 19.33 | |
| Number of rainy days decreased | 28.85 | 38.67 | |
| The intensity of rainfall increased | 4.33 | 2.00 | |
| The occurrence of untimely rainfall increased | 5.23 | - | |
| Drought occurrence increase | 2.40 | 36.67 | |
| Temperature increased in the last 15 years: | | | 13.55*** |
| Yes | 87.02 | 90 | |
| No | 2.88 | 8.00 | |
| Stayed the same | 7.69 | 2.00 | |
| Don't know | 2.40 | - | |
| Local perceptions of temperature variability: | | | 36.38*** |
| Number of hot days increased | 76.92 | 78.33 | |
| The number of warm nights increased | 2.00 | 3.33 | |
| The coldness of cold seasons decreased | 7.21 | 5.33 | |
| Rainfall comes on time last summer | | | 28.06*** |
| On-time | 16.82 | - | |
| Too early | 1.44 | 1.33 | |
| Too late | 81.73 | 98.66 | |
| Rainfall stop on time last summer | | | 11.84*** |
| On-time | 7.21 | 0.00 | |
| Stopped too late | 0.96 | 2.00 | |
| Stopped too early | 91.82 | 98.00 | |
| Rain during the harvest time last year | | | 42.88*** |
| Yes | 24.52 | - | |
| No | 75.48 | 100 | |

[¥] percentage does not add up to 100 because of multiple responses.

*** significantly different at $P < 0.01$

## 2.6. Meteorological variability and trends of rainfall and temperatures

### 2.6.1. Variability of rainfall

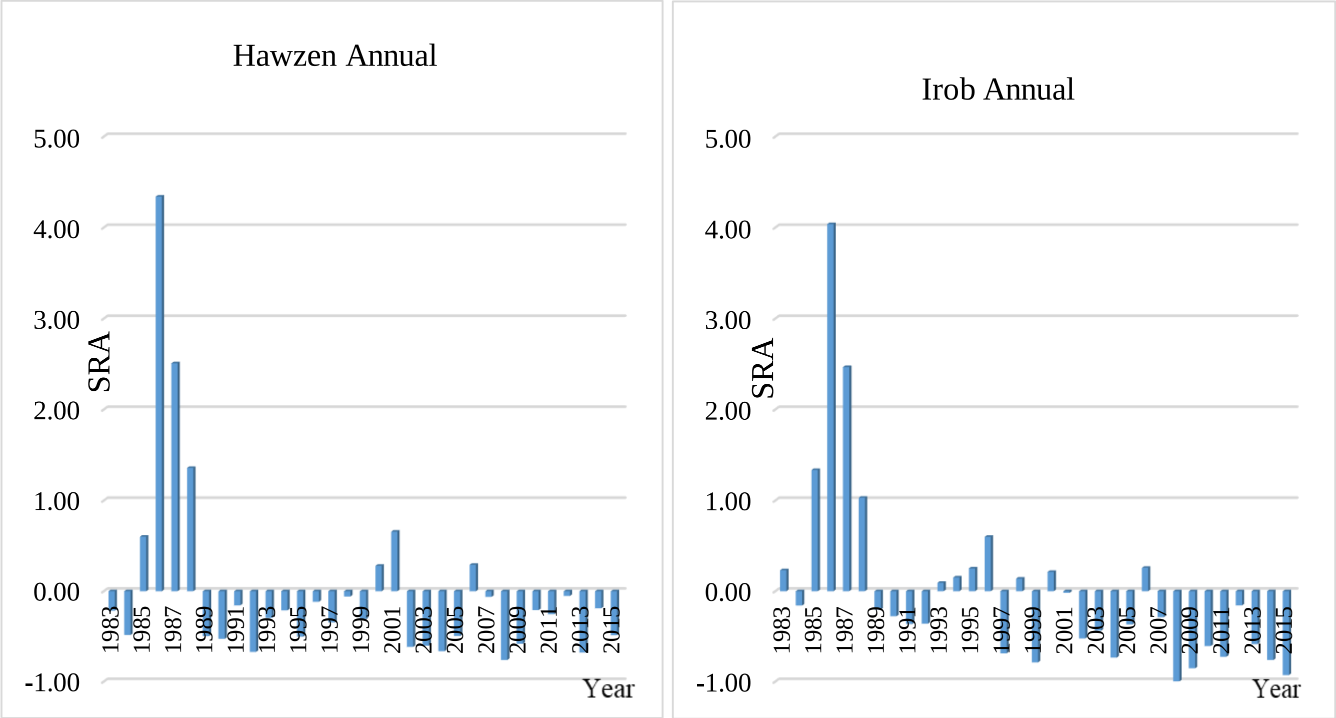
Seasons were defined using the standard meteorological definition: Spring (March, April, and May) and summer (June, July, and August) consistent with Belihu *et al.* (2017). Table 2.5 illustrates that the long-term mean annual rainfall varies from about 614 mm in Hawzen to 471mm in Irob respectively during the period of analysis analogous with semi-arid climate zone of northern Ethiopia (Nyssen *et al.*, 2005). Kiros *et al.* (2016) found that 555mm and 633mm mean annual rainfall for Hawzen district and northern Tigray region over the period 1971-2013 respectively. Summer, the main rainy season, and spring, the short rainy season, rainfall contribute around 69 percent and 19 percent in Hawzen. Likewise, it was contributed 50 percent and 33 percent to mean annual rainfall in Irob. Hence, about 88 percent and 83 percent of the total annual rainfall occurs in the two seasons in the study area. Summer rainfall dominates the seasonal pattern, and spring also considerably contributed to the annual rainfall in north Tigray (Conway, 2000). The contribution of spring rainfall over the north and northeastern highlands is ranging from 5 percent to 30 percent (Cheung *et al.*, 2008).

The long-term mean annual and seasonal rainfall was unevenly distributed in both districts. High long term mean annual rainfall variability ranges from 48 percent in Hawzen to 59 percent for Irob, respectively. A rainfall amount with CV above 30 percent is an indication both districts are vulnerable to drought (NMA, 1996). Hadgu *et al.* (2013) consistently reported a high CV in annual and main rainfall season in Tigray, northern Ethiopia. Summer CV is less than spring CV in both districts, indicating that summer rainfall was relatively less variable than spring rainfall. Higher rainfall variability is experienced during the small rainy season than the main rainy season and annual rainfall (Pohl and Camberlin, 2006). Rainfall variability and uncertainty in semi-arid areas have a substantial influence on agricultural production (Nyssen *et al.*, 2005).

The annual SRA analysis showed that there were 8 and 6 very dry and 10 and 4 dry years in Hawzen and Irob, respectively throughout the analysis. Edwards and McKee (1997) suggested that 3 or 12-month accumulated rainfall SRA is calculated to determine the seasonal and intermediate-term drought index. Drought occurs when the SRA initially drops below zero and ends with the first positive value (McKee *et al.*, 1993). For annual rainfall, the proportion of negative anomalies ranges from 63 percent to 79 percent while for summer rainfall ranges from 63 percent to 61 percent in Irob and Hawzen of the total observations, respectively. Consistently, rainfall has been declining in the Northeast Ethiopia since 1996 (Verdin *et al.,* 2005). Maximum and minimum annual rainfall was recorded in 1986 and 2008 while summer rainfall was observed in 1986 and 1992 years, respectively in both districts. This indicated that rainfall was gradually declined during the period of analysis.

Table 2.5 Max, Min, Mean (μ), standard deviation (σ) and CV annual rainfall from 1983-2015

| Annual and seasonal rainfall | Hawzen | | | | | Irob | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Max | Min | Mean | $\sigma$ | CV | Max | Min | Mean | $\sigma$ | CV |
| Annual | 1890 | 390 | 614 | 294 | 48 | 1602 | 192 | 471 | 280 | 59 |
| Spring | 569 | 21 | 118 | 111 | 94 | 613 | 19 | 153 | 119 | 78 |
| Summer | 1257 | 224 | 426 | 185 | 43 | 972 | 88 | 236 | 156 | 66 |


Hawzen Annual

Irob Annual

Figure 2.1 Temporal variations of annual SRA from 1983 - 2015

### 2.6.2. Trend of rainfall

The monotonic trend of temperature and rainfall time series were measured using the MKT assuming no serial correlation in the data set. The most widely applied test for detecting serial correlation is the Durbin-Watson $d$ statistic that is defined as the ratio of the sum of squared differences in successive residuals to the residual sum of squares (Gujarati, 2009). Before the MKT, serial correlation analysis for rainfall and temperature were assessed using the Durbin-Watson $d$ statistic. The estimated Durbin-Watson $d$-statistic values were above one and less than 2, hence not rejecting the null hypothesis suggesting that there is statistically significant evidence of positive autocorrelation in the residuals.

The trend test for annual and seasonal rainfall did not show statistically significant results in both districts (Table 2.6). Negative trends were evident in both annual and seasonal rainfall except for a positive trend observed in the summer rainy season for Hawzen. In Hawzen and Irob, annual rainfall has been decreasing by about 32.38 and 121.33mm per decade during the period of analysis. However, a statistically insignificant weak increment by about 7.7 mm per decade was observed in Hawzen main rainy season, though, the spring season was decreased by about 33 mm per decade (Table 2.6). Farmers' perception mainly depends on the lack of rainfall that required for normal agricultural production (Speranza, 2010).

The findings of this study agree with other studies previously applied in other parts of Ethiopia. More specifically, Kiros *et al.* (2016) found a mix of positive and negative trends with no statistically significant trends at Geba River Basin in the Tigray region, northern Ethiopia over 1971-2013. However, they revealed an insignificant increasing trend in the main rainy season in Wukro and Abiadi districts (adjacent to Hawzen). Consistently, Hadgu *et al.* (2013) found an insignificant mixed trend in both annual and seasonal rainfall in Tigray region, northern Ethiopia between1980 and 2009.

Moreover, they reported that the main rainy season which contributes 62 percent to the total annual rainfall was insignificant increasing, though, annual rainfall decreased in *Edagahamus* town (near to study area). Overall, Conway (2000) and Cheung *et al.* (2008) reported a non-significant declined trend of annual and seasonal rainfall in northern Ethiopia.

Table 2.6 Trends of annual and seasonal rainfall from 1983-2015

| District | Annual rainfall (mm) | | | | Main rainy season (mm) | | | | Spring season (mm) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Kendall's tau | Kendall's S | P-value* | Sen's slope | Kendall's tau | Kendall's S | P-value | Sen's slope | Kendall's tau | Kendall's S | P-value | Sen's slope |
| Hawzen | -0.170 | -90.00 | 0.916 | -3.238 | 0.053 | 28.00 | 0.285 | 0.766 | -0.371 | -196.00 | 0.999 | -3.328 |
| Irob | -0.481 | -254.00 | 0.500 | -12.133 | - 0.352 | -186.00 | 0.998 | -3.904 | -0.496 | -262.00 | 1.000 | -5.422 |

*(two-tailed) test

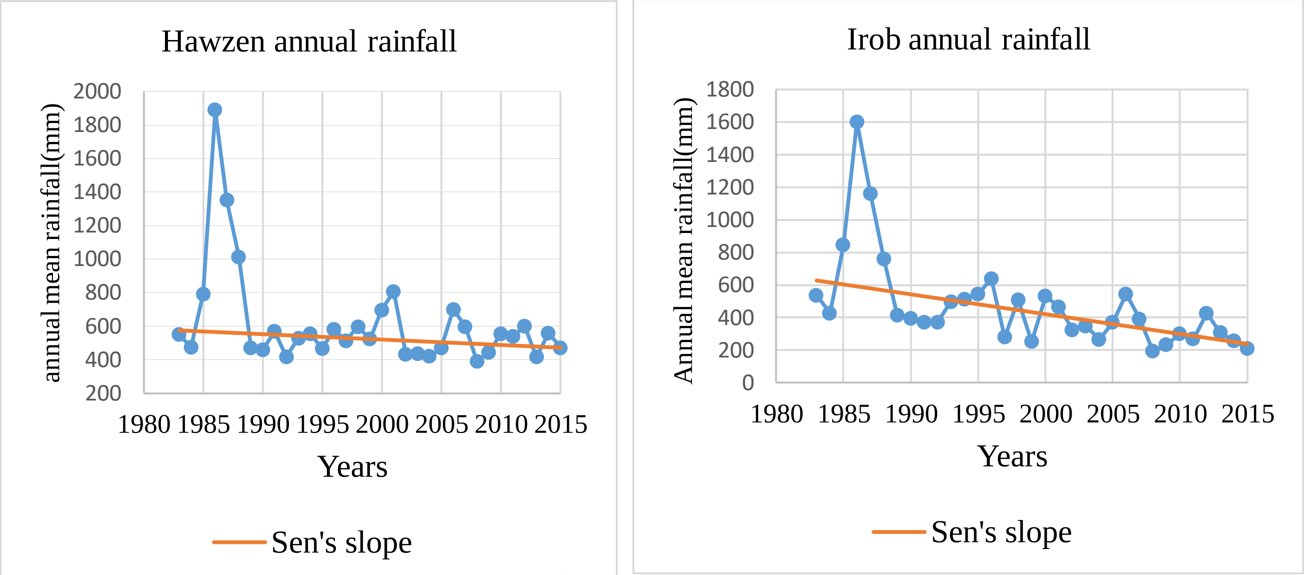


Figure 2.2 Annual rainfall trends Irob from 1983-2015

### 2.6.3. Variability of temperature

The mean annual temperature data was computed as an average of the maximum and minimum temperatures. Mean ($\mu$) and standard deviation ($\sigma$) values of temperature during the study period are presented in Table 2.7. The mean maximum ($T_{max}$), minimum ($T_{min}$), and annual temperature ($T_{mean}$) were 27.06$^0$C, 11.30$^0$C, and 19.18$^0$C for Hawzen. Correspondingly, 27.96$^0$C, 11.88$^0$C, and 19.92$^0$C were for Irob respectively for the time of analysis. Irob had been recording slightly higher mean temperatures compared to Hawzen district. In Hawzen, the lowest and the highest mean annual temperature variability was 25.61$^0$C and 28.38$^0$C recorded in 1986 and 2013, respectively. Likewise, 26.86$^0$C and 30.00$^0$C were the lowest and highest temperatures recorded in 1989 and 2008 for Irob, respectively implying, that temperature was rising in both districts. In Hawzen, spring and summer were the hottest and coldest seasons that reported 20.73$^0$C±0.96$\sigma$ and 9.73±0.67$\sigma$, while in Irob, summer and winter were the hottest and coldest seasons with 22.45$^0$C±0.69$\sigma$ and 17.96$^0$C±0.68$\sigma$, respectively.

Table 2.7 Annual and seasonal maximum, minimum and mean temperature from 1983-2015

| Annual and seasonal | T max ($^0$c) | | | | T min ($^0$c) | | | | T mean | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Hawzen | | Irob | | Hawzen | | Irob | | Hawzen | | Irob | |
| | $\mu$ | $\sigma$ | $\mu$ | $\sigma$ | $\mu$ | $\sigma$ | $\mu$ | $\sigma$ | $\mu$ | $\sigma$ | $\mu$ | $\sigma$ |
| Annual | 27.06 | 0.70 | 27.96 | 0.65 | 11.30 | 0.60 | 11.88 | 0.62 | 19.18 | 0.65 | 19.92 | 0.64 |
| Spring | 28.85 | 1.06 | 28.70 | 0.97 | 12.60 | 0.85 | 12.85 | 0.75 | 20.73 | 0.96 | 20.78 | 0.86 |
| Summer | 25.86 | 0.72 | 29.61 | 0.72 | 13.60 | 0.63 | 15.28 | 0.65 | 9.73 | 0.67 | 22.45 | 0.69 |
| Autumn | 26.47 | 0.85 | 27.61 | 0.61 | 10.14 | 0.76 | 10.45 | 0.76 | 18.31 | 0.81 | 19.03 | 0.67 |
| Winter | 27.06 | 0.71 | 25.91 | 0.89 | 8.85 | 0.64 | 8.93 | 0.67 | 17.96 | 0.68 | 17.42 | 0.78 |

### 2.6.4. Trends of temperature

Warming trends in maximum and annual mean temperatures were observed for Hawzen and Irob districts at statistically significant levels ($P<0.01$ and $P<0.05$), respectively. The warming trends of maximum and mean annual temperatures were 0.65$^{0}$C and 0.40$^{0}$C per decade in Hawzen. Likewise, the warming trends in maximum and mean annual temperatures were 0.55$^{0}$C and 0.39$^{0}$C per decade in Irob for the period of analysis, respectively. Generally, the mean annual temperature trend was increased by about 1.32$^{0}$C and 1.29$^{0}$C for Hawzen and Irob, respectively in the period of analysis (Table 2.8 and Figure 2.3). Moreover, the maximum temperature increased faster than the minimum temperature for both districts. However, Gebrehiwot and Van Der Veen (2013) found the average annual minimum temperature (0.72ºC) increased faster than the average annual maximum temperature (0.36ºC) per decade in the Tigray region northern Ethiopia during the period 1954-2008.

Table 2.8 Trends in annual and seasonal temperature from 1983-2015

| District | T max ($^{0}$c) | | | | T min ($^{0}$c) | | | | Mean T ($^{0}$c) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Kendall’s tau | Kendall’s S | P-value* | Sen's slope | Kendall ’s tau | Kendall’s S | P-value | Sen's slope | Kendall’s tau | Kendall’s S | P-value | Sen's slope |
| Hawzen | 0.685 | 340.00 | 0.0001 | 0.065 | 0.181 | 90.00 | 0.140 | 0.025 | 0.500 | 248.00 | 0.001 | 0.040 |
| Irob | 0.657 | 326.00 | 0.0001 | 0.056 | 0.181 | 90.00 | 0.153 | 0.027 | 0.492 | 244.00 | 0.001 | 0.039 |

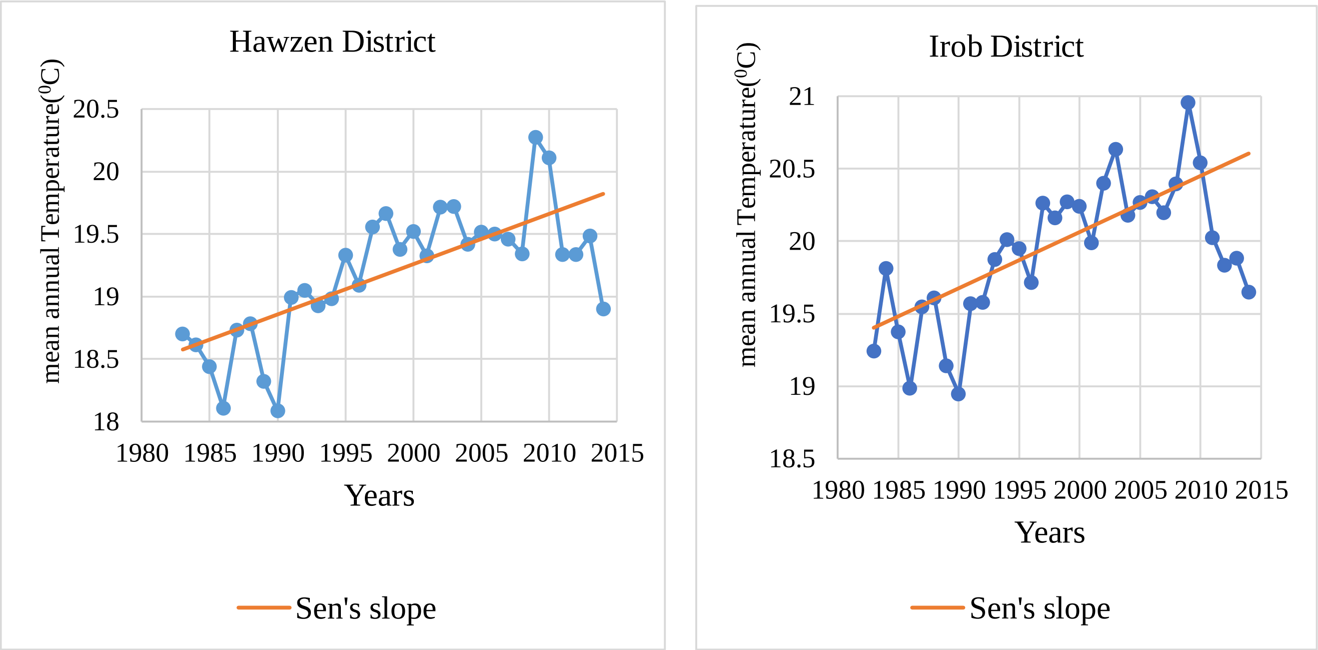


Figure 2.3 Trends of annual mean temperature from 1983-2015

## 2.7. Econometrics model results

The Heckman probit model confirmed that all the independent variables are free from the multicollinearity problem using the Variance Inflation Factor (VIF) and contingency coefficient (*Annex 1.6-Annex 1.8*). Further, the Heckman probit model at the beginning was tested for its fitness and explanatory power over the standard probit model. As a result, the Heckman probit model results showed that the existence of sample selection problem (dependence of the error terms from the outcome and selection models) prove the application of the model with *rho* significantly different from zero (Wald $\chi^2$= 4.46, with $P < 0.05$). Furthermore, the likelihood function of the Heckman probit model was significant (Wald $\chi^2$= 35.74, with $P < 0.01$), confirmed its strong explanatory power.

Tables 2.9 presents the marginal effect of the outcome and selection Heckman probit model results along with the levels of statistical significance. The calculated marginal effects measure the expected changes in the probability of adaptation and perception for a unit change in an independent variable from the mean value, other things remained unchanged. Age of household head, family size, access to agricultural extension services (AES), number of off-farm activities, and access to climate information was positively and statistically significant to influence farmers' WSC adaptation decisions. However, a decrease in annual rainfall trends had a positive and statistically significant influence on farmers' WSC adaptation decisions.

Based on the model results, a unit increase in household head age results in a 0.4 percent increase in the probability of adopting WSC adaptation measures. Gbetibouo (2009) suggested that older farmers have long farming experience and easily capable to recognize the nature of modern technology than younger farmers that influence the decision to take adaptation measures. This result is in agreement with the findings of Deressa *et al*. (2011); Alemayehu and Bewket (2017). The probability of WSC adaptation decisions increased by about 3 percent for each additional household member. This result is in harmony with the results of Kassie *et al*. (2009); Ojo and Baiyegunhi (2019) who suggested that large economically productive household members preferred the adoption of labor-intensive agricultural technologies including WSC in Africa.

Access to AES significantly increased the likelihood of WSC adaptation decisions by 13.6 percent. This finding aligns with previous studies of Shiferaw *et al.* (2014); Alemayehu and Bewket (2017). According to these authors, AES help to deliver agricultural technologies and weather information for farmers that ultimately enhance adaptation responses at the local level. A one-unit increase in off-farm activities has increased the probability of WSC adaptation decisions by about 8 percent. Fernandez-Cornejo and Mishra (2007); Gbetibouo (2009) found results that indicated households with access to off-farm activities were more likely to adopt WSC measures. Correspondingly, farmers with more access to climate information were more likely to increases the adaptation decisions by 1 percent. This collaborates the findings of Asrat and Simane (2010); Moroda *et al.* (2018) who argued that farmers with better access to climate information more likely to invest in adaptation measures by growing their confidence about the forthcoming weather conditions.

Local climatic conditions and agro-ecological conditions are expected to influence farmers' adaptation decisions hence, annual mean rainfall and temperature trends included in the model. The result of the model showed that a decreasing rainfall amount significantly increases the probability of adaptation decisions. More specifically, a 1mm decrease in annual rainfall trend below the mean long term rainfall trend increased the probability SWC adaptation decision by 2.7 percent. This finding is in agreement with the findings of Deressa *et al*. (2011) who found an indirect relationship between rainfall and SWC adaptation decisions to address the adverse impacts of climate change in rural Ethiopia.

Table 2.9 Results of the Heckman probit selection model

| Independent variables | **outcome model** (dummy:1 adapted and 0 otherwise) | | | | **Selection model** (dummy: 1 if perceived and 0 otherwise) | | | |
|---|---|---|---|---|---|---|---|---|
| | Regression | | Marginal effect | | Regression | | Marginal effect | |
| | Coeff. | Std. Err. | Coeff. | Std. Err. | Coeff | Std. Err. | Coeff. | Std. Err. |
| Sex (male=1) | 0.018 | 0.241 | 0.005 | 0.066 | -0.234 | 0.036 | | |
| Age (years) | 0.015* | 0.*008* | 0.004* | 0.002 | 0.004 | 0.009 | | |
| Education (years) | 0.033 | 0.033 | 0.009 | 0.008 | -0.014 | 0.036 | | |
| Family size (AE) | 0.105** | 0.*055* | 0.030** | 0.014 | -0.031 | 0.055 | | |
| Livestock holding (TLU) | -0.043 | *0.056* | -0.012 | 0.015 | 0.038 | 0.059 | | |
| Access to AESs (yes=1) | 0.459** | 0.260 | 0.136** | 0.071 | 0.443** | 0.262 | 0.094** | 0.055 |
| Off farm activities (number) | 0.293** | 0.154 | 0.080** | 0.041 | -0.062 | 0.147 | | |
| Access to weather information | 0.325** | *0.256* | 0.010** | *0.070* | 0.585** | *0.258* | 0.124** | *0.054* |
| Drought frequency last ten years | *0.008* | *0.034* | 0.002 | *0.009* | *-0.030* | *0.034* | | |
| Farm size (*tsimad*) | 0.053 | 0.176 | 0.015 | 0.048 | -0.097 | 0.188 | | |
| Fertile plot (*tsimad*) | 0.197 | 0.184 | 0.054 | 0.049 | 0.030 | 0.172 | | |
| Training at FTC (yes=1) | -0.052 | 0.190 | -0.014 | 0.052 | -0.321* | 0.201 | -0.068* | 0.042 |
| Chemical fertilizer (quintal) | 0.089 | 0.295 | 0.024 | 0.081 | 0.129 | 0.310 | | |
| Distance to market (min) | 0.003 | 0.002 | 0.001 | 0.001 | 0.002 | 0.002 | | |
| Social networks (number) | | | | | 0.202*** | 0.070 | 0.043*** | 0.014 |
| Annual rainfall trend | -0.099* | 0.055 | -0.027* | 0.015 | -0.133** | 0.059 | -0.028** | 0.012 |
| Annual temperature trend | 0.393 | 0.1.07 | 1.076 | 0.0.29 | 2.723 | 0.115 | | |
| AEZ (*Weinadega*) | 0.258 | 0.279 | 0.070 | 0.076 | 0.333 | 0.294 | | |
| Constant | -3.719 | 0.342 | | | -1.545 | 0.71 | | |
| Total observations | 358 | | | | | | | |
| Censored | 54 | | | | | | | |
| Uncensored | 304 | | | | | | | |
| Wald Chi-square (Zero slopes) | 35.74, (P< 0.01) | | | | | | | |
| Wald Chi-square ( independent equations) | 4.46, (P <0.05) | | | | | | | |

***, **, * significance levels at P<0.01, P<0.05 and P<0.1 respectively

## 2.8. Conclusions and recommendations

Limited access to meteorological information for agricultural activities increases farmer's vulnerability to climate change impact. Consequently, farmers rely on perception to obtain reliable and accurate climate information. However, integrating farmers' perceptions with observed meteorological data and its influence on adaptation measures have not extensively studied in Ethiopia. Therefore, the present study investigates farmers' perceptions of rainfall and temperature changes with observed long term meteorological information and its influence on adaptation strategies in Hawzen and Irob. Primary data were collected from 358 randomly selected farm household heads supplemented with Gridded annual rainfall and temperature data ranged from 1983 to 2015.

The study revealed that despite a statistically significant difference was showed between districts majority of the households have been perceived as a changing climate and extreme events in their locality. Results showed that 98.56 percent and 92 percent perceived a decrease in rainfall amount in Hawzen and Irob respectively. Specifically, farmers realized the manifestation of rainfall variability through an increase in variability in onset and cessation time of the rainy season, the number of rainy days decreased, and drought frequency. Moreover, 87 and 90 percent of households' felt that the temperature was increased in Hawzen and Irob, respectively. The perceived increased temperature evidenced by the increasing number of hot days, warm nights, and decreased coldness of cold seasons. The findings from the analysis of meteorological data showed a decreasing trend of annual rainfall and increasing temperature congruent to farmer's perception.

The modified MKT test revealed that annual rainfall has decreased trend by about 32.38mm and 121.33mm per decade in Hawzen and Irob, respectively. The results also indicated that both annual and rainy seasons are highly variable with a non-significant trend in the study area. Nevertheless, a statistically significant ($P<0.01$) increase in mean annual temperature is observed by $0.4^0$C and $0.39^0$C per decade, respectively during the period of analysis. Therefore, this study confirmed that farmers' perceptions of climate change are mirror meteorological information that required for adaptation measures and preparedness for extreme weather events.

Moreover, this study employed the Heckman probit model to examine the two-step process of adaptation to climate change. Farmers' perception of climate change was significantly related to access to AES, weather information, training at FTC, social network membership, and annual rainfall trend. Households used different farming adaptation strategies to reduce climate and non-climate extreme impacts, though, SWC practice reported the dominant planned adaptation strategies in the study area.  Households WSC adaptation decision was significantly influenced by age of household head, household size, agricultural extension services, off-farm activities, weather information, and mean annual rainfall.

Based on the results of the study, the following recommendations can be suggested: First, to promote smallholder farmers' weather information processing ability delivering relevant and up-to-date information about climate variability and its impacts is required in FTC. Second, regional and local government should create an enabling infrastructure that facilitates the implementation of weather information and communication technology. Third, there is a need to form a partnership with different local organizations and informal social networks to disseminate weather information and respond to climate change impacts. Finally, both annual and seasonal rainfall has been declined tremendously hence, introducing drought-resistant crops, sowing short maturing crop varieties, and reschedule of the crop calendar in line with the growing season should be a top farm adaptation intervention in the study area.

# 3. Households' livelihood vulnerability to the changing climate and variability

## *Abstract*

*Limited efforts have been made to assess climate change vulnerability at the household level since its impacts are heterogeneous between communities. Therefore, this study measures households' vulnerability to climate variability in Hawzen and Irob districts. Primary data were collected from 358 rural households using a multi-stage sampling method. Gridded satellite annual rainfall and temperature data during 1983-2016 were also used to identify the long term trends. The Household Vulnerability Index was calculated as the net effect of sensitivity and exposure on the adaptive capacity. The respective weight of these sub-components was assigned using the principal component analysis method. Moreover, the K-means algorithm method was utilized to clustering households into distinct vulnerability profiles. The empirical result revealed that farm households in Hawzen had a higher adaptive capacity (1.358) compared to Irob (0.791). Furthermore, households in Hawzen showed lower exposure index value (0.109) compared to Irob (0.605) while both groups reported an equal sensitivity index. Therefore, the overall net Household Vulnerability Index for Hawzen (0.875) was higher than those in the Irob district (-0.188) indicates that Hawzen had a relatively lower vulnerable than Irob to climate variability. Moreover, the K-means cluster analysis exhibited that 26 percent of households fell within the highly vulnerable while 47 and 27 percent were moderate and less vulnerable to climate change and variability, respectively. Hence, policies should aim to further increase adaptive capacity through human capital development by providing education and persistent training on adaptation measures to moderate climate change impacts. Moreover, increasing the livelihood capitals of the highly vulnerable households group by providing public emergency assistance.*

**Keywords:** Vulnerability, livelihood, principal component analysis, cluster analysis.

## 3.1.Introduction

Global climate change and rising income inequality between the poor and the rich are the main development challenges expected to govern economic and social policy in the twenty-first century (Gowdy and Salman, 2008; Delgado and Li, 2016). Climate change is one of the most significant threats that damage the human community's livelihood, ecosystem services, and rising energy demand (Nematchoua *et al.*, 2019; Mehvar *et al.*, 2019 Abdelzaher *et al*., 2020). Rural smallholders in many developing countries are extremely challenged by extreme climate change risks because they depend heavily on agriculture for their livelihood inherently sensitive to adverse effects of climate variability and change (McCarthy, 2001; Goulden *et al.,* 2013). This challenge is especially severe when taken in the setting of global attempts to achieve Sustainable Development Goals in rural regions (United Nations, 2016).

Global temperatures in 2018 were 0.83$^0$C warmer than the mean 1951 to 1980 following the year 2016, 2017, and 2015. The average global temperature of the earth during 2015 was 0.75 °C above the average temperature for the 1961-1990 period (Met Office Meteorological Office, 2016). According to the IPCC (2018) in the last century the average global temperature raised by about 1$^0$C mainly due to fossil fuel burning and deforestation. Further evidence suggested that, assuming the new scenarios (IPCC, 2013) average air temperature over the period 2081-2100 will be 0.3°C -4.8°C higher than that during 1986-2005.

Africa is the most susceptible to climate change due to the overdependence of the economy in the climate-sensitive sectors of agriculture (Orimoloye *et al.,* 2019; Steynor and Pasquini, 2019). Rural smallholders in many developing countries depend heavily on natural resources for their livelihoods (Goulden *et al.,* 2013). Temperatures in Africa are expected to increase faster than the global average during the 21st century. Congruently, in Ethiopia the mean annual temperature raised by approximately 1.3°C between 1960 and 2006, an average rate of 0.28°C per decade (IPCC, 2013). The annual and seasonal rainfall changes in Ethiopia do not show clear trend changes, but temperature warming in all four seasons across the country (Conway and Schipper, 2011). Conversely, the northern part of Ethiopia exhibited a significant decline in rainfall and a rise in temperatures than the national average by 0.25ºC per decade (Gebrehiwot and Van Der Vaan, 2013).

Historically, Ethiopia is one of the most drought-prone and highly vulnerable countries to climate change since 250 BC, which has seriously damaged its economic development (Ramakrishna and Demeke, 2002; Abera *et al*., 2019). Ethiopia has evidenced twelve extreme droughts that affected the livelihoods of over 50 million people in the 20th century (Gidey *et al.*, 2018). More specifically, the World Bank (2006) estimated that the 1984/85 Ethiopia faced the worst drought reduced agricultural production by about 21 percent, equivalent to a 9.7 percent decline in GDP. UNDP (2013) revealed that Ethiopia would lose 7-8 percent of GDP per year due to adverse climate change risk impacts that have a decisive impact on the livelihood of the rural poor household. Further, Robinson *et al.* (2013) predicted that Ethiopia would loss 8-10 percent GDP smaller than under a no-climate change baseline by 2050. The General Circulation Models (GCMs) forecast over Ethiopia predicts that the magnitude and frequency of climate change and variability related impacts are likely to increase in the future (Kiros *et al*., 2016).

Assessing vulnerability to climate change and variability is helpful to planning and implementing adaptation strategies that combat climate change vulnerability impacts (Krishnamurthy *et al*., 2014). Particularly, households are excited to know the current vulnerability context to stemmed and adapt using different response strategies (Eakin and Bojorquez-Tapia, 2008; Hahn *et al.* 2009). With this motivation, climate change vulnerability measurements have been framed at various units of analysis. The empirical studies on measuring vulnerability to climate change to different factors have been made at the global scale (Ericksen *et al.*, 2012), national scale (Brooks *et al*., 2005); regional scale (Abson *et al.*, 2012), and district scales (Piya *et al.*, 2012; Adu *et al.*, 2018). However, these studies focused on measuring relative climate change vulnerability at a macro level. Vulnerability assessments at the national and regional scales are inadequate because it is varying across temporal scales, an exception with large extreme weather events and entitlements are unevenly distributed (Adger *et al*, 2004; Smit and Wandel, 2006).

Currently, several authors have been suggested the measurement of household-level vulnerability to climate change within a district or region (Gebrehiwot and Van Der Veen, 2013; Deressa, 2010). The decision to manage climate change vulnerability is primarily the responsibility of households’ hence measuring vulnerability to climate change at the household level has received important attention (Thomas *et al*., 2007; IPCC, 2012). Analyzing vulnerability at the household level can help to understand climate change vulnerability threats and the adaptation strategies applied to create a resilient livelihood outcome (Linnekamp *et al.,* 2011). Moreover, it helps to promote the general understanding of who is vulnerable to climate change impacts and for what reason.

However, past studies on vulnerability to climate change in Ethiopia have mostly been carried out at the higher scale disregarding household-level data (Deressa *et al*., 2008; Simane *et al.*, 2014). Yet, these studies could mask significant local-level variability because households are unequal in terms of access to assets, response strategies, exposure, and entitlements (Busby *et al*., 2014). Moreover, vulnerability is specific to place, economic, socio-demographic, and institutional factors (Smit and Wandel, 2006; Eakin and Bojorquez-Tapia, 2008). Therefore, macro-level studies have failed to adequately measure the local level differentiation that will modify climate change impacts except determining vulnerable groups within a specific geographical area (Eakin and Luers, 2006). Empirical evidence from Ethiopia also confirms social and spatial variations are the sources of variation for households' vulnerability to climate change and variability (Edeshaw, 2014; Simane *et al*., 2014; Dendir and Simane, 2019). Moreover, Eakin and Bojorquez-Tapia, (2008) underlined that addressing this limitation is helpful to understand the degree of households' vulnerability to climate change impacts.

Despite measuring household vulnerability to climate change has become a growing field of research there are few empirical studies in northern Ethiopia. Recently, Mekonnen *et al.* (2019) assess the vulnerability of households and agro-ecosystems and the determining factors to climate change in the central rift valley, Ethiopia. Therefore, the present study fills the gap in the literature by using household data to analyze farm households' vulnerability to climate change and variability employing the livelihood vulnerability frameworks in semi-arid Eastern highlands of Tigray, northern Ethiopia. Specifically, this study involves twofold main objectives: (i) measure farm households' livelihood vulnerability to climate change and variability (ii) classifying household's into three distinct vulnerability categories with a particular cross-comparison between Hawzen and Irob Districts.

### 3.2. Determinants of household livelihood vulnerability

"Livelihood comprises the capabilities, assets, and activities required for a means of living" (Chambers and Conway, 1992:7). The range and combination of these activities and choices that people make to achieve their life goals are referred to as livelihood strategies (DFID, 1999). According to the sustainable livelihood framework (SLF) livelihood assets are combined to generate livelihood strategies with particular outcomes (Ellis, 2000). This study utilized the framework at the household level assuming households combine capital assets to moderate livelihood vulnerability. Because, the livelihood vulnerability is influenced by the entitlement to the essential capital asset, which supports in improving the ability to overcome climate shocks. These livelihood capitals are social, human, financial, natural, and physical referred to as the asset base of the community and different categories of households (FAO, 2005). However, for Scoones (2015) SLF has critical limitations such as failure to consider the long-term environmental threats including climate change and coping with long-term shifts in rural economies and agrarian change, among others.

Social capital has the attributes of social organizations like civic participation, norms of reciprocity, and trust that ease cooperation for mutual benefit (Putnam *et al.*, 1993). Carrillo Álvarez and Romaní (2017) described social capital as a resource available to individuals and groups due to membership in a social network. Therefore, households' groups with better participation in community-based organizations and social networks have a tendency to reduce vulnerability to climate change and extremes. Human capital involves both innate and learned skills, and the ability to process information which affects rural households' performance to implement the various livelihood strategies (Jamison and Lau, 1982; Pour *et al.,* 2018). It referred to the size of household labor, skills, knowledge, ability to work, and good health services that determine the quantity and quality of the available labor to utilize the other capitals (Scoones, 1998; Li *et al.,* 2017).

Financial assets primarily referred to monetary sources such as saving, family income, and access to credits from formal and informal sources, livestock endowment, production equipment and technologies (Asfaw *et al.*, 2013; Quandt, 2018). Poor households have limited financial assets but they can convert their capital assets such as natural capital during extreme weather events to keep consumption fluctuations. Households with livestock endowments are useful as a buffer stock to protect consumption fluctuations during climate extremes (Li *et al.*, 2017). Livestock assets and access to credit significantly improved pastoralists' resilience to climate change and variability in rural Ethiopia (Mekuyie *et al.,* 2018).

Natural capital is a sort of natural environment useful to produce income, goods and services to human well-being (Fenichel, 2013). Specifically, it refers to land, water, and quality of the environment that can be immediately utilized for production to support livelihood sources. Rural poor households primarily depend on natural resources to generate income and secure their livelihood. Physical asset is a vital livelihood asset which is essential for production processes (Pour *et al.*, 2018). It includes households' productive and non-productive assets like infrastructure, water and sanitation systems, and means of production (FAO, 2005). Physical capital is not only measured by the availability of tangible resources but the extent household's easily accessed these assets (Quandt, 2018). Households preferred a balanced capital asset to maintain adaptive capacity and well-being, but there are overlaps and tradeoffs between the five livelihood capitals (Quandt, 2018). Therefore, differences in livelihood assets endowments and the capacity to access these capital assets determine households' choices of livelihood strategies (Hua *et al*., 2017). The five capital assets have a critical positive influence on small-holders adaptation measures to moderate climate change impacts in SSA (De Jalón *et al*., 2018).

The sensitivity variables were selected based on the livelihood strategy that households choose to depend on the climate-sensitive sectors to achieve their livelihood goals. Recurrent droughts and floods accounted for 80 percent and 70 percent for the loss of life and economic crisis in SSA (Bhavnani *et al.*, 2008). Moreover, rainfall variability has a critical impact on the livelihoods of the poor in most African countries (Hellmuth *et al.*, 2007). A higher rate of change in rainfall and temperature will increase the household's exposure and sensitivity to climate change and extreme events in Ethiopia.

## 3.3. Methodology

### 3.3.1.Data sources

Primary data that determine rural household's livelihood vulnerability to climate change and variability generated from Hawzen and Irob districts. Secondary data on annual maximum temperature and annual rainfall between 1983 and 2016 for each *Kebeles* were obtained from NMAE to determine the trends.

### 3.3.2. Standardization and weighting of HVI

PCA method produces a single index from the complex interactions between various dimensions allowing to use continuous variables that follow a multivariate normal distribution (Vega and Fuente, 2013). Kaiser-Meyer-Olkin (KMO) statistics is a measure of sample adequacy which varies from 0 to 1 and values closer to 1 are better. Hair *et al.* (2006) suggest accepting a value of 0.5 or more values are good. Bartlett's test of sphericity is a statistical test for the presence of correlations among variables that requires rejecting the null hypothesis that suggests the correlation matrix is an identity matrix. Thus, a significant Bartlett's test of sphericity is required, say $P \leq 0.05$. The choice of a factor to be retained is one of the most crucial decisions in PCA to develop valid constructs. Field (2000) proposed to retain only those factors with an eigenvalue greater than 1(EVG1) or holding the factors in which cumulative account for about 70-80 percent of the variance and make a scree-plot graph retain all factors before the breaking point.

However, Cliff (1988) claims there was no rationale in practice retaining as many factors as there were eigenvalues greater than one. The factor rotation simplifies the factor structure hence makes its interpretation simple and more reliable (Cattell, 1978). The most common rotations methods are oblique rotations that allow for correlation and orthogonal rotations that assume the factors are not correlated. Both methods include algorithms to conduct rotations: varimax, quartimax, equamax, direct oblimin and promax. The first three options are orthogonal rotation while the last two oblique rotations algorithms. The varimax rotation method, developed by Kaiser (1958), is certainly the most popular rotation method by far that was also employed in this study.

Cluster analysis is a type of unsupervised learning method for statistical analysis that divides a data set into meaningful and useful clusters hence the observation is similar and the cluster is dissimilar from other clusters (Adolfsson *et al*, 2018). Majhi and Biswal (2018) underlined that the choice of the optimal algorithm depends on the characteristics of the dataset. Hence, the *K*-Means algorithm is the most widely used among the non-hierarchal cluster analysis methods due to its simplicity and computational efficiency (Fraiman *et al.*, 2013). However, using this non-hierarchical cluster analysis should decide an arbitrary number of cluster centers (Nielsen *et al.*, 2013).

The HVI indicator method used to measure vulnerability systematically comprise the selected indicators based on literature to indicate the degree of vulnerability to climate change and variability (Piya *et al.*, 2012; Mekonnen *et al.*, 2019). The HVI method measures the comparative ranking of households' vulnerability to climate change and extreme events based on IPCC (2007) vulnerability definition. The HVI was calculated using the following mathematical formula that involves the three main components of vulnerability:

$$Vulnerability(v_i) = (adaptive\ capacity) - (exposure\ +\ sensitivity\ ) \qquad (2.1)$$

Equation (2.1) revealed when the adaptive capacity of the household exceeds exposure and sensitivity components the household is labeled as less vulnerable to climate changes and extremes and the reverse is true. In short, the model was calculated using the following equation

$$v_i = \left(A_1X_{1j} + A_2X_{2j} + \cdots + A_nX_{nj}\right) - \left(A_{n+1}Y_{1j} + A_{n+2}Y_{2j} + \cdots + A_{n+n}Y_{nj}\right) \qquad (2.2)$$

Where, $v_i$ is the vulnerability index, while $X_s$ are elements of adaptive capacity, and $Y_s$ are elements of exposure and sensitivity while $A_i$ is the principal component result of the factor score. The values of *X* and *Y* are obtained from different indices measured at different scale then, it is necessary to standardize each as an index to ensure the comparability of indices (Deressa, 2008). Hence, all the variables were normalized by subtracting the mean from the observed value and dividing by the standard deviation for each indicator (Abson *et al.*, 2012).

$$X_{1j} \ = \ (x_{1j} - x^{*}{}_{1}) \ \ /S_1{}^{*} \qquad (2.3)$$

Where, $x_{1j}$ is the observed value, $x_1{}^*$ and $S_1{}^*$is the mean and standard deviation of the original value of $X_{1j}$ across the different households respectively. After standardized the indicators, PCA was used to assign different weights to the indicators in order to overcome the limitations of equal weighting given the diversity of indicators of adaptive capacity, sensitivity, and exposure (Deressa, 2008; Piya *et al.*, 2012).

$$I_J = \sum_{i=1}^{k} A_i \ (x_{1j} - x_1{}^{*}) \ /S_1{}^{*} \qquad (2.4)$$

The vulnerability index for a household was standardized between 0 and 1 inclusive. That is, 0 represents high vulnerable and 1 represents low vulnerable households. The standardized variables were then adding to provide a final vulnerability index that allows cross-comparison with the PCA based vulnerability indices (Abson *et al.*, 2012).

Table 3.1 Major components and sub-components of vulnerability

| Major components | Sub-components | Explanation of sub-components | Unit of measurement |
|---|---|---|---|
| Social capital | Education | Years spent on education by HH | Year/s |
| | Family size | Total number of a family member | AE |
| | Dependency ratio | Aged below 15 and above 65 to age between 15-65 within the household | Ratio |
| | Social network | HH membership to CBO and networks | Number |
| | Food-self sufficiency | HH find food from own production range:(0-12) | Months |
| Human capital | Access to health facility | Walking distance to the nearest health center | Minutes |
| | Access to health insurance | HHs with CBHI | Percentage |
| Natural capital | Livelihood diversification index (range: 0.125-1) | The inverse of the number of agricultural livelihood activities +1 | Ratio |
| | Farmland size | HH total landholding | *Tsimad* |
| | Fertile plot | Share of fertile land to total farmland | *Tsimad* |
| Financial capital | Access to credit | HHs total credit received | EBR |
| | Livestock size | HH total livestock size | TLU |
| Physical capital | Access to the potable water | Walking distance to the nearest potable water | Minutes |
| | Access to all-weather roads | Walking distance to the nearest motor road | Minutes |
| | Access to schools | Walking distance to the nearest school | Minutes |
| | Access to a veterinary center | Walking distance to the nearest veterinary center | Minutes |
| Sensitivity | Livestock death | Livestock death by drought in the last10 years | Number |
| | Farmland damaged | Farmland damaged by a flood in the last 10 years | Tsimad[1] |
| Exposure | Temperature | rate of change in average annual temperature | Coefficient of trend |
| | Rainfall | rate of change in average annual rainfall | Coefficient of trend |

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[1] *Tsimad* is an area of land approximately equal to a quarter of a hectare.

## 3.4. Results and Discussion

### 3.4.1. Sample household characteristics

Statistically significant differences in livelihood capital between Hawzen and Irob districts were observed (Table 3. 2). The analysis of variance (ANOVA) test confirmed that the average number of social networks, household's food self-sufficiency, and an average time to reach health facility for medical care was advanced in Hawzen than in Irob. Moreover, households from Hawzen reported higher average farm size, fertile plot, and access to credit than their counterparts. Moreover, the average time spends to reach rural infrastructures was small for households in Hawzen. Conversely, households' from the Irob district reported statistically significant large livestock death and farmland damage compared with households from Hawzen district. A significant decrease in annual rainfall and an increase in temperature was reported in both districts, respectively.

Table 3.2 Summary statistics variables used in the model

| Variables | Aggregate | | Hawzen | | Irob | | P-value |
|---|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD | |
| Education | 2.26 | 2.98 | 2.08 | 2.89 | 2.50 | 3.10 | 0.196 |
| Family size | 4.59 | 1.70 | 4.53 | 1.67 | 4.67 | 1.75 | 0.428 |
| Dependency ratio | 0.91 | 0.86 | 0.96 | 0.84 | 0.85 | 0.90 | 0.221 |
| Social networks | 1.41 | 1.53 | 1.91 | 1.63 | 0.72 | 0.40 | 0.000 |
| Food self sufficiency | 3.54 | 2.76 | 5.00 | 2.63 | 1.52 | 1.23 | 0.000 |
| Access to health facility | 38.57 | 33.88 | 21.81 | 16.01 | 61.82 | 38.18 | 0.000 |
| Access to health insurance | 62.64 | 21.76 | 62.99 | 21.98 | 62.17 | 21.53 | 0.727 |
| Farm size | 1.30 | 0.77 | 1.71 | 0.72 | 0.75 | 0.40 | 0.000 |
| Fertile plot | 0.36 | 0.53 | 0.51 | 0.62 | 0.15 | 0.24 | 0.000 |
| Access to credit | 2896 | 4913 | 4253 | 5704 | 1014 | 2546 | 0.000 |
| Livestock size | 2.65 | 1.74 | 2.59 | 1.73 | 2.72 | 1.76 | 0.478 |
| Access to potable water | 22.85 | 24.78 | 9.91 | 28.65 | 40.81 | 8.15 | 0.000 |
| Access to all weather road | 30.53 | 35.02 | 11.40 | 14.42 | 57.08 | 37.80 | 0.000 |
| Access to school | 38.24 | 33.96 | 21.41 | 16.01 | 61.03 | 38.80 | 0.000 |
| Access to veterinary center | 31.66 | 35.97 | 11.43 | 59.72 | 59.72 | 37.92 | 0.000 |
| Livestock death | 2.86 | 4.62 | 1.03 | 2.28 | 5.40 | 5.73 | 0.000 |
| Farm land damage | 0.19 | 0.38 | 0.13 | 0.30 | 0.29 | 0.45 | 0.000 |
| Temperature increase | 0.0519 | 0.0041 | 0.0549 | 0.0025 | 0.0478 | 0.0018 | 0.000 |
| Rainfall decrease | -6.5348 | 3.3106 | -3.7703 | 0.5089 | -10.3683 | 0.6616 | 0.000 |

$P < 0.01$, statistically significant level at 1percent

### 3.4.2. PCA results

The adequacy of the model was examined using the KMO measure of sampling adequacy and Bartlett's test before using factor analysis. The analysis showed that the KMO measure of sampling adequacy is about 0.85 (Table 3.3) and the Bartlett test of Sphericity for these data is highly significant (P<0.01) verifies the model as fairly acceptable (Henry *et al.* 2003).

Table 3.3 KMO- Bartlett test

| | | |
|---|---|---|
| Kaiser-Meyer-Olkin measure of sampling adequacy | | 0.847 |
| Bartlett test of Sphericity | | |
| | Chi-square | 405.69 |
| | degrees of freedom | 190 |
| | P-value | 0.000 |

The PCA analysis reported that seven components with eigenvalues greater than 1 together explained about 70 percent of the total variation in the data set. The first principal component explained about 31 percent of the variation hence factor retention would continue till EVG1 has been exhausted. To calculate HVI of adaptive capacity, sensitivity, and exposure variables that are positively linked to PCA were reported. Thus, to make the overall vulnerability index 20 of the 27 indicators were kept for further analysis based on the absolute value of their factor score greater than or equal to the 0.5 within the exposure, sensitivity and adaptive capacity indicators (Mekonnen *et al.*, 2019).

Except for agricultural livelihood diversification, all the factor scores of PCA results were directly related to the indices of vulnerability in the direction as expected (Table 3.4). This indicated that households with a positive index have relatively higher adaptive capacity compared to a household with a negative sign other things remain constant and vice versa (Deressa, 2008; Opiyo *et al.,* 2014). Indices with a higher magnitude of factor score indicated higher importance, hence contributes more to the household's adaptive capacity. Higher dependency ratio (i.e., more household members with less than 15 and above 65 years old) in rural Ethiopia context does not infer a person out of working age in practice, indeed they are part of the labor force and help to support livelihood strategies. Recently, the dependency ratio in rural Ethiopia dropped from 105 percent in 2014 to 100 percent in 2016 due to a decline in fertility rate (CSA, 2013; 2016). Finally, household adaptive capacity and the overall HVI were calculated using equation (2.4).

Table 3.4 Retained factor score and standardized HVI

| Vulnerability indices | Factor score | Hawzen<br>Standardized value | Irob<br>Standardized value |
|---|---|---|---|
| Education | 0.561 | 0.272 | 0.004 |
| Family size | 0.491 | 0.005 | 0.150 |
| Dependency ratio | 0.905 | 0.055 | 0.019 |
| Food self sufficiency | 0.725 | 0.011 | 0.010 |
| Social networks | 0.599 | 0.035 | 0.000 |
| Access to health facility | 0.943 | 0.094 | 0.074 |
| Access to health insurance | 0.663 | 0.031 | 0.002 |
| Farm land size | 0.767 | 0.146 | 0.010 |
| Fertile plot | 0.642 | 0.046 | 0.000 |
| Access to credit | 0.807 | 0.020 | 0.006 |
| Livestock holding (TLU) | 0.766 | 0.320 | 0.360 |
| Access to potable water | 0.693 | 0.153 | 0.024 |
| Access to all weather roads | 0.702 | 0.043 | 0.040 |
| Access to school | 0.943 | 0.094 | 0.047 |
| Access to veterinary center | 0.849 | 0.032 | 0.034 |
| Livestock death | 0.704 | 0.235 | 0.123 |
| Farm land damaged | 0.821 | 0.139 | 0.251 |
| Temperature increase | 0.456 | 0.103 | 0.365 |
| Rainfall decrease | 0.589 | 0.005 | 0.241 |
| Eigenvalue | 1.020 | | |
| Proportion | 0.051 | | |
| Cumulative | 70.08 | | |

### 3.4.3.Adaptive capacity

The adaptive capacity is composed of sixteen sub-components categorized into five capital assets. The results revealed that the adaptive capacity indices of the sub-components ranged from 1.358 in Hawzen to 0.791 Irob (Table 3.5). This implies that households' from Hawzen had relatively better adaptive capacity to respond to climate change and variability impacts than households in Irob, other things remain unchanged.

**Social capital**

The socio-demographic profile consisted of five subcomponents (Table 3.2). Households' from Irob had slightly higher average education enrollment and family size than Hawzen (Table 3.2). Education promotes households' access to weather information and boosts adaptation measures than their counterparts (Adu *et al.*, 2018). Large family size is important for labor-intensive adaptation practices including WSC and crop diversification where labor to land ratio is lower

(Bryan *et al.,* 2009). But the dependency ratio was higher in Hawzen 0.96 compared to Irob 0.85 these dependent members in rural Ethiopia are involved in economic livelihood activities like in many developing countries. Hahn *et al*. (2009) found that a higher dependency ratio in Ghana helps to reduce climate change-induced risks.

On average, households from Hawzen had nearly 2 social networks proxy by CBO in local *Kebele* compared to 0.72 in Irob. Households with higher social networks and membership in local organizations easily access agricultural technologies and facilitate the risk-sharing process between members during climate-induced shocks (Kassie *et al.,* 2013; Bedeke *et al.*, 2019). As a result, households from Hawzen districts showed a higher socio-demographic profile index (0.379) than Irob (0.184) in all the sub-components, except the family size helpful to ameliorate climate change and variability impacts, other things remain constant.

**Human capital**

Two subcomponents are included in the human capital major component (access to human health facilities and CBHI). Hawzen showed a high health facility index (0.094) than Irob (0.074) based on time took to reach the nearest health center. This could be justified by households in Hawzen spent on average about 22 min to reach the nearest health center for medical care compared to 62 min in Irob. In June 2011, the Government of Ethiopia declared a pilot CBHI scheme in rural parts of the country to enhance health care use. Households with CBHI afford primary health services that reduce the high medical treatment expenditures, thereby improved household labor qualities and knowledge of agricultural technology adoption (Mebratie *et al*., 2019). Moreover, in terms of access to health insurance Hawzen showed a higher index (0.031) than Irob (0.002). Because households in Hawzen reported slightly higher CBHI 63 percent compared to 62 percent in Irob. Generally, Hawzen recorded a higher adaptive capacity index (0.126) than Irob (0.077) to ameliorate climate change-induced impacts (Table 3.5).

**Natural capital**

The natural capital asset is composed of two indexes, specifically farmland size and fertile land plots that are a proxy measure of wealth and farm stability in rural Ethiopia essential for livestock and labor-intensive farming practices (Mutyasira *et al.,* 2018). On average, households from Hawzen owned large farm size and fertile plots 1.71 and 0.51 *tsimad* which is less than half of the average land size to the national 1 hectare (CSA, 2008) compared to Irob 0.75 and 0.15, respectively. Crop production is higher in fertile plots compared to poor fertile plots most likely exposed to soil erosion and low production (Bedeke *et al*., 2019). Therefore, keeping the indicators that constitute the natural capital asset, households from Hawzen had a higher natural capital with a calculated index of (0.191) as compared to (0.010) for the households in Irob (Table 3.5).

**Financial capital**

This major component consists of two indicators include access to microcredit and TLU. Households from Hawzen received on average 4253 than 1014EBR in Irob from rural microfinance last one year, respectively. Access to credit may reduce household cash shortage and improve the adoption of capital intensive adaptation strategies to ameliorate climate change impacts (Wainaina *et al*., 2016). Hawzen showed more credit index from rural microfinance (0.020) than Irob District (0.006). However, in terms of livestock holding households from Irob owned 1.76 TLU compared to 1.73 TLU in Hawzen. As a result, Irob reported greater TLU indices of (0.360) than Hawzen (0.320). Livestock endowment facilitates farm-level adaptation and protects consumption fluctuations during climate extreme hazards (Li *et al*., 2017). When the two financial capital sub-components were aggregated households from Hawzen district relatively showed lower financial capital with index value (0.340) than Irob (0.366) to reduce climate change impacts.

**Physical capital**

Four indicators are included in the physical capital sub-component. Considering the average time a household took to reach the basic rural infrastructural facilities as a benchmark a great difference was shown between the two districts (Table 3.2). On average, households in Hawzen took about 10 min with score index of (0.153) to reach the nearest potable drinking than 41 min in Irob with a score index of (0.024) where the majority of families depend on natural water supply. On average, households took 11 min with an index score of (0.043) to reach all-weather roads in Hawzen than 57 min in Irob with an index score of (0.040). Similarly, on average households took 21min with an index score of (0.094) to reach the nearest school in Hawzen than 61 min with an index score of (0.047) in Irob. On average, households took 11 min with an index of (0.032) to get to the nearest veterinary center compared to 59 min with an index score of (0.034) in Irob, respectively. Lack of access to veterinary facilities aligned with the fact that about 85 percent of the households in Irob reported that the death of livestock in the past ten years was the second-worst climatic shock (Table 5.2). The low physical access in Irob was inconformity with FGD and personal observations.

Access to basic rural physical capital assets improves weather information dissemination, reduced climate change adaptation barriers, and the work burden of household members in rural Ethiopia (Kaliba *et al.,* 2000; Deressa *et al.,* 2009). Generally, aggregating the four sub-components of physical capital households from Hawzen showed a higher index (0.323) than Iorb (0.155) indicated that Hawzen had relatively better access to physical capital that moderate climate change and variability impacts, other things remain constant (Table 3.5).

### Sensitivity

The sensitivity major components constitute two sub-components namely livestock death and the size of farmland damaged by a flood. Consistent with the three worst shocks households had experienced over the last ten years include drought 70 percent, livestock death 60.06 percent, and flood 43.58 percent respectively (Table 5.2). Drought devastates rural households in Africa and leads to crop loss and death of livestock (Njiru, 2012). Likewise, the semi-arid Eastern highlands of Tigray is severely damaged by soil degradation that caused recurrent drought and food insecurity (Gebremeskel *et al.,* 2018). Furthermore, Berhane *et al.* (2016) advocated that Tigray is exposed to periodic extreme events of droughts and floods.

The number of livestock deaths by climate change extremes shocks such as drought was higher in Hawzen with an index value of (0.235) than Irob (0.123) in the past ten years this indicated that Hawzen was more sensitive to climate change extreme shocks. In contrast, Irob showed higher farmland damaged with index value (0.251) than Hawzen (0.139) caused by a flood. Because, Irob topography is characterized by rugged mountains, hills, and high plateaus with altitudes range from 900 at *Endeli* valley to 3,229 m.a.s.l. Asimba Mountain leads to susceptible soil degradation and high rainfall variability. Generally, when the two sub-components were aggregated both Districts generated the same index value (0.374) for the number of livestock death and farmland damage as a result of recent natural hazards. This result justifies that both districts mainly depend on rain-fed mixed farming as livelihood sources and have similar agro-climatic zones that adversely sensitive to climate change and variability.

### 3.4.4.Exposure

The exposure major components comprise two sub-components include annual rainfall and temperature trends. Both variables have increased households' exposure to climate change and extreme events. The mean annual temperature measured by the coefficient of trend showed an increasing trend since 1983 on average 0.5°C per decade in Hawzen compared to 0.48°C for Irob proxy by each Kebeles. However, the weighted standardized value of the annual temperature trend was higher in Irob (0.365) than Hawzen (0.103). In Irob annual rainfall trend was showed a decreasing trend on average 103.67 mm with a score value of (0.365) than 37.7 mm in Hawzen with a score value (0.005) per decade. Generally, when aggregating the two sub-components of exposure index value Irob was found highly exposed (0.605) than Hawzen (0.109) to climate change and variability impacts.

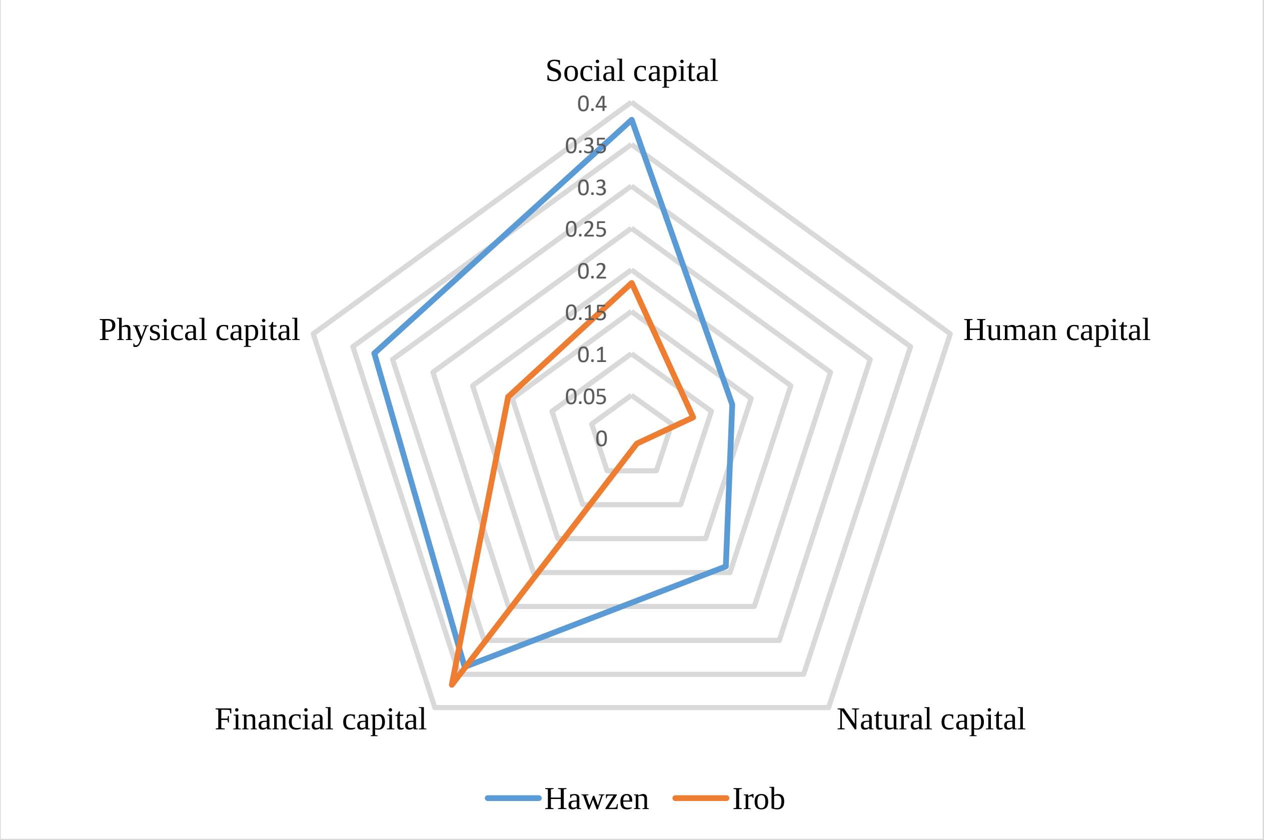

Figure 3.1 Adaptive capacity index spider diagram of major components

0.0= most vulnerable, 0.4 = least vulnerable

### 3.4.5.Overall HVI: contributing factors

The overall HVI for each household was calculated by applying equation 2.4 considering the three contributing factors to CC vulnerability adaptive capacity, sensitivity, and exposure. Going on this equation, where adaptive capacity exceeds exposure and sensitivity yields lower vulnerability while when exposure and sensitivity exceed adaptive capacity results in high vulnerability. As a result, the index value of adaptive capacity was found higher (1.358) than sensitivity and exposure (0.483). This implies that households from Hawzen were relatively lower vulnerable to climate change and variability impacts (Table 3.5 and Figure 3.2). Contrary, the index value of sensitivity and exposure components was higher (0.979) than the adaptive capacity (0.791) for households in Irob. Overall, the net vulnerability value (-0.188) implied that households in Irob were relatively more vulnerable to climate change and variability compared to households in Hawzen.

Table 3.5 HVI weighted scores and vulnerability contributing factors

| Major Components | Subcomponents | Subcomponents weighted value | Major component Weighted value | Weighted HVI | t-test |
|---|---|---|---|---|---|
| Adaptive capacity | Social capital | 0.379(0.184) | 1.358(0.791) | 0.875(-0.188) | $6.97^a$<br>df 356 |
| | Human capital | 0.126(0.077) | | | |
| | Natural capital | 0.191(0.010) | | | |
| | Financial capital | 0.340 (0.366) | | | |
| | Physical capital | 0.323(0.155) | | | |
| Sensitivity | Livestock death | 0.235 (0.123) | 0.374(0.374) | | |
| | Farm land damaged | 0.139 (0.251) | | | |
| Exposure | Temperature increase | 0.103(0.365) | 0.109(0.605) | | |
| | Rainfall decrease | 0.005(0.241) | | | |

Values in the parenthesis are for Irob district, $^a$ significance level at P<0.01 *df* = degree of freedom

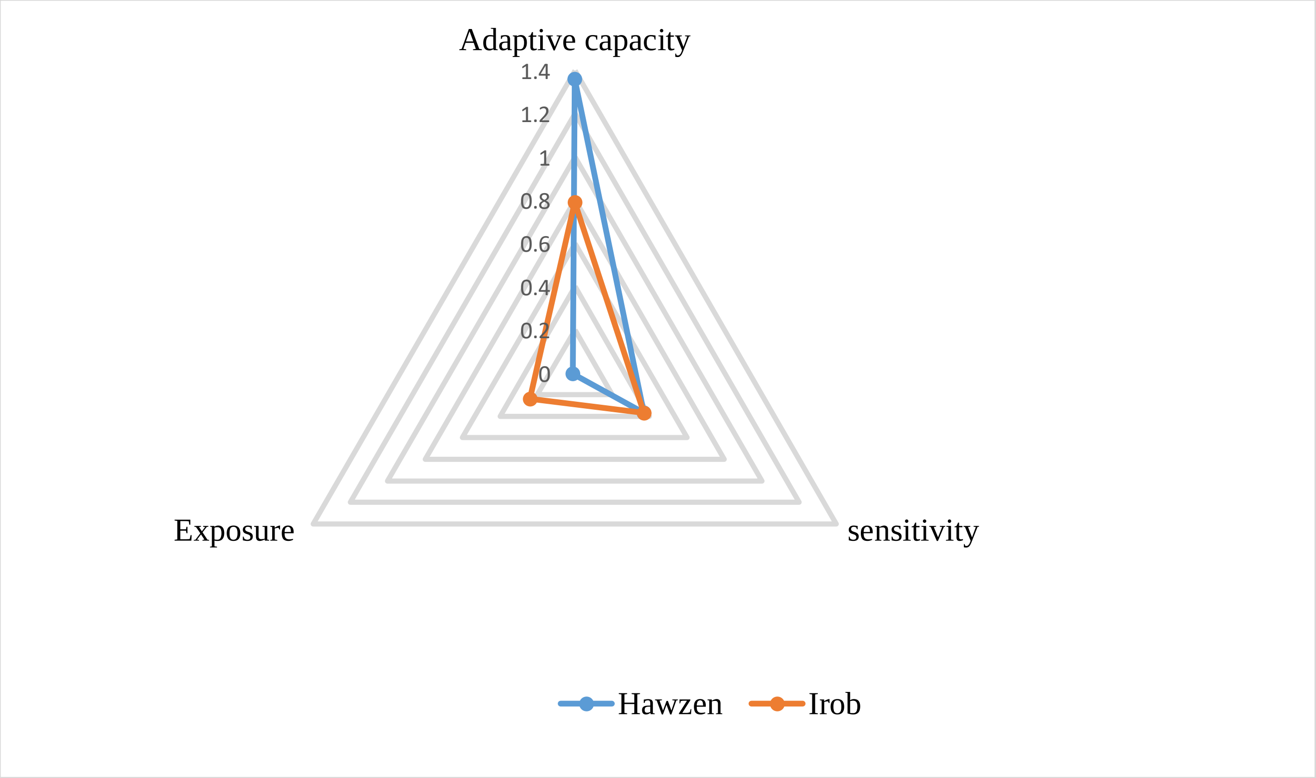

Figure 3.2 Vulnerability triangle diagram of the major components of HVI

0.0 = Low contributing factor, 1.4 = high contributing factor

K-means cluster analysis was applied to classify households into three major vulnerability categories using the vulnerability index inspired by Opiyo *et al.* (2014). Table 3.6 shows that about 26 and 47 percent of households fall under high and moderate vulnerable category while 27 percent of the sampled households remained less vulnerable to climate change and extreme weather events respectively. Furthermore, the result revealed that a statistically significant ($P$<0.001) difference between the three vulnerability index category in the study area.

Table 3.6 Inter households vulnerability classification

| Vulnerability profile | Brief description | Number | percent | mean | SD | P-value |
|---|---|---|---|---|---|---|
| Highly vulnerable | Emergency level households | 94 | 26.26 | -4.92 | 1.75 | 0.000 |
| Moderately vulnerable | Need urgent but temporary external assistance to recover | 167 | 46.65 | -0.09 | 1.41 | |
| Less vulnerable | In a vulnerable situation but still able to cope | 97 | 27.09 | 4.91 | 2.63 | |

$P$ < 0.01 indicates significant at 1% significance level

Table 3.7 presents the relation between variables included in the model and vulnerability index categories. As a result, households with better education easily access weather information and use adaptation measures to reduce vulnerability to climate change variability than their counterparts (Deressa *et al.,* 2009; Adu *et al*., 2018). Large family size is helpful for labor-intensive adoption practices and crop diversification hence it improves adaptive capacity helpful to reduces adverse climate shocks (Bryan *et al.,* 2009; Asfaw *et al.,* 2013). The higher dependency ratio in rural Ethiopia context helps households through access to family labor since the family members engage in livelihood activities. Moreover, studies from household vulnerability to climate change in Ghana and Mozambique reported consistent results (Hahn *et al.*, 2009; Adu *et al.,* 2018).

Households with better, social networks and membership in local farmer organizations can access agricultural technologies and allows risk-sharing between members during climate-induced shocks compared to their counterparts (Kassie *et al.,* 2013; Bedeke *et al.,* 2019). Households' owned CBHI afford primary health services access and reduce the high medical treatment expenditures then improves household labor qualities and knowledge for agricultural technology adoption. Therefore, the promotion of the health status of people living in rural communities through rural health insurance systems must top policy agenda of government (Chen *et al.,* 2018).

Households with fertile plots perceived better returns without much investment in adoption practices to CC impacts (Boansi *et al.,* 2017). Nevertheless, crop production is higher in fertile plots compared to poor fertile plots most likely exposed to soil erosion and low production (Bedeke *et al*., 2019). Livestock asset endowment providing higher net income from selling animal products thereby improves the resilience of households during adverse climate change and variability (Wainaina *et al.,* 2016; Mekuyie *et al.*, 2018). Moreover, households with access to microcredit services reduce their cash shortage and increase engagement in capital intensive adaptation strategies to ameliorate climate change impacts compared to their counterparts (Wainaina *et al*., 2016).

Rural physical capital is particularly public goods and utilities provide by the public to enhance the welfare of rural households based on the non-exclusiveness principle. Hence, access to physical capital is not provided in favor of particular households rather supplied equally to all local communities located in a central area.

Table 3.7 Description of subcomponent variables by vulnerability categories

| Vulnerability variables | Household vulnerability categories | | | P-value |
|---|---|---|---|---|
| | less vulnerable | moderate vulnerable | high vulnerable | |
| Education | 2.93 | 2.45 | 1.22 | 0.000 |
| Family size | 4.77 | 4.91 | 3.84 | 0.000 |
| Dependency ratio | 1.05 | 0.98 | 0.65 | 0.002 |
| Social network | 1.86 | 1.32 | 1.11 | 0.002 |
| Food self-sufficiency | 3.97 | 3.42 | 3.31 | 0.189 |
| Access to a health facility | 68.45 | 34.59 | 15.60 | 0.000 |
| Access to health insurance | 67.28 | 65.85 | 52.16 | 0.000 |
| Farmland size | 1.32 | 1.33 | 1.23 | 0.568 |
| Fertile plot | 0.43 | 0.40 | 0.21 | 0.005 |
| Access to credit | 3019 | 3343 | 1977 | 0.093 |
| Livestock holding (TLU) | 3.57 | 2.71 | 1.58 | 0.000 |
| Access to potable water | 39.84 | 20.59 | 9.34 | 0.000 |
| Access to all-weather roads | 51.98 | 28.42 | 12.15 | 0.000 |
| Access to school | 68.45 | 34.14 | 14.32 | 0.000 |
| Access to veterinary center | 57.61 | 28.36 | 10.74 | 0.000 |
| Livestock death | 3.72 | 2.95 | 1.81 | 0.016 |
| Farm land damaged | 0.16 | 0.21 | 1.82 | 0.501 |

$P < 0.01$ and 0.05 significance level at 1and 5 percent respectively

### 3.5.Conclusion and recommendation

This study examined the household's livelihood vulnerability to climate change and variability using an integrated vulnerability assessment approach in Hawzen and Irob districts. Household Vulnerability Index was calculated as the net effect of sensitivity and exposure on the adaptive capacity. Finally, the respective weight of these sub-components was assigned using the principal component analysis method.

The results of the study revealed that farm households' in Hawzen had a higher adaptive capacity compared to those in Irob besides they reported lower exposure compared to Irob. However, both households reported an equal sensitivity value to climate change and variability. Therefore, the overall net HVI indicated that households in Hawzen are relatively less vulnerable than Irob to the impacts of climate change and variability. Moreover, the inter household vulnerability analysis showed that 26 percent of the households were highly vulnerable while 47 and 27 percent found under moderate and less vulnerable to climate change and variability impacts, respectively. Households with better education enrollment, large family size, high dependency ratio, more social network, food self-sufficiency, fertile plot, and livestock holding, among others found less vulnerable than their counterparts.

Based on the findings of the empirical study the following recommendations can be forward. First, local government organizations and NGOs should promote households' human capital and ease access to financial inclusion programs to reduce household vulnerability. Second, community-based WSC adaptation measures should encourage to restore farmland fertility and reduce severe land degradation, particularly manifested in Irob district. Third, basic public investment would be the top priority of the local government organizations to recover the welfare of the marginalized households located in Irob districts. Eventually, the local government should provide emergency food aid and strengthen the existed PSNP to protect highly vulnerable households.

# Chapter Four

## 4. Vulnerability of households' to food insecurity and its influencing factors

***Abstract***

*An ex-post measure of food security method observed the current access to food, but fail to indicate the likelihood of remaining or becoming food insecure soon. This study dedicated to the ex-ante approach employed a three-step Feasible Generalized Least Square and Foster-Greer-Thorbecke techniques to examine the determinants and decompose households' vulnerability to food insecurity to climate change and variability in Hawzen and Irob districts. A multistage sampling method was employed to select 358 rural households supplemented with secondary data. The food energy intake measurement method was applied to analyze the factors that determine households' vulnerability to food insecurity. Keeping the food poverty line, about 82 and 87 percent of households were considered food insecure in Hawzen and Irob districts, respectively. Therefore, the food-insecurity gap suggested that at least 42 and 58 percent, an increase in mean food consumption expenditure was required to maintain food security. Moreover, about 78.5 percent of households were categorized as chronically food insecure while 1 percent of households had a stable food security status. Future food consumption expenditure was increased with dependency ratio, livestock size, irrigation potential, livestock death, energy cost, and positive annual rainfall trend in Degamba Kebele whereas it decreased with family size and negative annual rainfall trend in Alitena Kebele. Therefore, local government should emphasize not only on households that are currently food insecure but also on those households expected to be food insecure in the coming year through promoting food security resilience.*

**Keywords:** Food security**,** ex-ante analysis, food energy intake, FTG, 3FGLS

## 4.1. Introduction

Climate change and variability are the modern-day threat of major food security components (IPCC, 2014). Globally, the incidence of undernourishment has increased from 10.6 in 2015 to 10.9 percent in 2017 correspondingly Africa's undernourishment raised from 18.6 percent to 20.4 in the same year. Moreover, the SSA undernourished population increased from 21.1 percent in 2015 to 23.2 percent in 2017 (FAO, 2018). Globally, one in nine people and a quarter of those in SSA is unable to secure their dietary energy requirements in 2014/15(FAO, 2015). Moreover, about one-third of the population was affected by severe food insecurity in 2016 (FAO, 2018).

Nelson *et al.* (2009) predict that child malnutrition will be raised by 20 percent compared to a world without climate change in 2050. Therefore, the number of people at risk of hunger will surge by 10-20 percent in 2050 with 65 percent of this population from SSA. But without the effect of global climate change, food demand is forecasted to increase by about 300 percent by the year 2080 intensified by higher population growth, income, and demand for bio-fuel energy sources (Cline, 2008). This imbalance between food demand and supply is a big obstacle to the United Nations Sustainable Development Goals (SDG) aims to "end hunger, achieve food security and improved nutrition" for all people by 2030. This is especially witnessed in SSA countries which are known by high climate variability (Hwang *et al.*, 2013).

Ethiopia has a long history of food insecurity and malnutrition caused by erratic rainfall and socio-political stresses though the prevalence of undernourishment (insufficient calorie intake) reduced from 39.7 percent to 25.7 between 2004-06 and 2015-17 (FAO, 2018; Desta *et al.*, 2020). However, yet about 8.5 million people were food insecure need urgent emergency food aid in 2017 (FAO, 2018). In Ethiopian, the periodic meteorological droughts damaged the rained dependent agriculture (Tesfamariam *et al.*, 2019). Consistent with these authors, Demeke *et al.* (2011) affirmed that rainfall variability is a significant factor in determining a household's vulnerability to food insecurity in rural Ethiopia.

Unstable food consumption is the characteristic of a poor rural household hence the current food secure households may shift into chronic food insecurity soon due to extreme climate change in many developing countries (Chaudhuri, 2003). Therefore, the current food security analysis disregards those households becoming food-insecure soon (Günther *et al.*, 2009; Capaldo *et al.*, 2010). Unambiguously, this is the main feature of poor households whose livelihood capital depends on the climate-sensitive rain-fed agriculture sector and low adaptive capacity to reduce the extreme weather event risks.

Empirical evidence from Ethiopia confirms that a 10 percent decline in seasonal rainfall from the long-term mean annual rainfall leads to a 4.4 percent decline in food production (Von Braun, 1991). The drought incidence becomes endemic every 3 to 5 years compared to every 2 or 3 a decades ago (Fitsum *et al.*, 2009). Dercon (2004) found that a10 percent decline rainfall before four to five years earlier had an impact of one percent current food consumption growth rates. Bogale (2012) showed that about 40 percent of households were vulnerable to food insecurity more than those who are currently food insecure 37 percent in Ethiopia. Moreover, Sileshi *et al.* (2019) estimated that nearly 54 percent of households were vulnerable to food insecurity more than those who are currently food insecure 36 percent in Ethiopia. This implies that analysis of current food insecurity neglects those households more likely to be food insecure soon though Ethiopia is most vulnerable to extreme weather events that lead to food security instability (Hunnes, 2015).

However, food security literature has been focused on current food security analyses providing less attention for vulnerability to food insecurity (Scaramozzino, 2006; Capaldo *et al.,* 2010). In Ethiopia, where food consumption is more volatile vulnerability to food insecurity will help to identify suitable policy interventions overtime (Oviedo and Moroz, 2014). Nevertheless, the literature on the conceptualization and measurements of food security was widely investigating current food security analysis (Coll-Black *et al.* 2012; Bishop, 2010; Mesfin, 2014). However, the current food security analysis overlooked the dynamic characteristics of food security. World Bank (2006) found that of the total population who are non-poor, the incidence of a single shock may result in another 25 percent to fall into poverty. Therefore, empirical studies based on current food security analysis unable to determine the future food security status except for classified households into food security or food insecurity (Capaldo *et al.,* 2010).

The current study differs from earlier studies in two main aspects. First, previous studies on vulnerability to food security focus on a single headcount index measure (Bogale, 2012; Megersa, 2015; Sileshi *et al.,* 2019). The head-count measures the proportion of households below a minimum threshold but it does not measure the depth and severity of food security status (Azeem *et al*., 2016). Second, prior studies focus on current food security analysis that leads to certain clear drawbacks. Therefore, this study has twofold objectives to address the limitations observed in food security analysis (i) decompose households' vulnerability based on food security status (ii) analyze the factors that determine households' vulnerability to food insecurity.

## 4.2. Concepts and measurements of food security

Food security has been continuing as a controversial topic in the literature on conceptualizing and theoretical frameworks (Jones *et al.,* 2013). The conceptual definition of food security in this study is grounded on the FAO's definition stemmed from FAO World Food Summit in November 1996: "food security exists when all people at all times, cause physical and economic access to sufficient, safe and nutritious food to fulfill their dietary needs and food preferences for an active and healthy life" (FAO, 2008:1). This broad definition includes important four key dimensions specifically physical availability, access, utilization, and stability (FAO, 2008). Particularly, these important dimensions are acknowledged as significant constituents that affect food security (Word Bank, 2001). All these dimensions are affected directly or indirectly by climate change and independent with each other (Vaitla *et al.,* 2017).

However, food insecurity is the limited access to one or more of the four dimensions and a manifestation of food vulnerability (Jones *et al*., 2013; Roncarolo *et al*., 2015). Climate change and variability affect food security through its influence on production and incomes which impedes food availability, access, utilization, and stabilization (FAO, 2018). Particularly, in Africa climate change caused intense crop pests (Duku *et al*., 2016). Climate change and variability impact agricultural production and food security by reducing crop yields (Bocchiola *et al*., 2019), fruit and vegetable crops (Leisner, 2020), livestock and marine fishers (Ding *et al*., 2017) and water resources (Gohar, and Cashman, 2016). The climate change impact on food security differs from region to region and over time, and also on the overall socio-economic conditions of the population (IPCC, 2001).

Food availability (the supply side of food security) is the oldest approach measured the physical quantity of food available in a country or household through all means of domestic production, food stocks, imports, and food aid in an open economy (WFP, 2009). It includes factors related to production, distribution, and exchange (FAO, 2008). The food availability concept refers to the

Malthusian approach which focused on the link between food availability (supply-side) and population growth (demand side) over time (Burchi and Muro, 2016).

Since the 1980s the Amartya Sen's entitlement approach has contested the Malthusian view and shifted the emphasis from national food availability to individual household's access to enough food. According to Sen (1981:434), food access defined: "It is not the characteristic of there being not enough food to eat." Moreover, unable to afford the entitlement that involves personal endowments and exchange entitlement leads to starvation. Specifically, food access encompasses elements of affordability, allocation, and preference (Gregory *et al.*, 2005). Food availability in a country may be sufficient, but there may be economic, physical, or socio-cultural barriers to obtaining food (Stephens *et al.*, 2018). For, Doppler (2002) the food utilization dimension refers to food holding all the required nutrients in it. According to FAO (2008) food system is referred vulnerable if at least one of the food security components is unstable and insecure.

Households' exposure to climate change reduces access to entitlements that reduce food security components (FAO, 2008). Food security protects hunger when it entails food stability (Napoli *et al.*, 2011). The food stability dimension is crucial to analyze the current and future status at different points in time to capture the temporal dynamics of food security (Løvendala and Knowles, 2005). Vulnerability to food insecurity is a forward-looking that refers to the propensity household's fall below a threshold line in the future (Babatunde *et al.*, 2008). Moreover, they argued that the likelihood of becoming food insecure in the future is influenced by current food security situations.

Efforts have been made to develop a single food security measurement that involves valid, specific, and comparable over time and space. However, yet there are no universally accepted measurements of food security due to the complexity of the concept (Smith *et al.*, 2017). For instance, Hoddinott (1999) states there are roughly 200 definitions and 450 indicators of food security. Furthermore, Riely and Moock (1995) identify 73 household food security indicators. Thus, measuring food security is very difficult that needs the use of several indicators since each indicator can capture different dimensions (Maxwell *et al*., 2013).

Food Balance Sheet (FBS) or FAO method is one of the oldest measurement food availability at the country level based on national food balance sheets on a per-capita basis (FAO, 2001; Headey and Ecker, 2013). The percentage of the food insecure population is determined who falls below a minimum energy requirement level after adjusted by an adult equivalent (AE) of the country's population (Torkelsson, 2003). The measurement of FBS is carried out by summing national food production and imports, and deducting food exports, food losses during harvest, food used for seeds, animal feed, and stock changes then adjusted into calories with each food calorie conversion factor. For instance, the Ethiopian government has adopted 2200 Kcal (225 kg of cereals per person per annum) as a minimum acceptable weighted average nutritional requirement (MoFED, 2002). Desiere *et al.* (2018) found congruent between FBS and household survey food security measurement in SSA. However, the method has sound limitations including, overlooking the quality of diet, obesity problems due to excessive calorie intake, and high measurement errors (Péreza and Segall, 2008).

Recently food availability assessment at the national level has been shifting attention to micro-level assessment using different techniques. The food energy intake (FEI) method emphasized entirely on food-based consumption in developing countries where a majority of the population spends a significant share of their income on food consumption (Bellù and Liberati, 2005). The method is based on household memory or recalls method over 1 day, 7 days or 30 days data, constructing the food calorie intake needed to lead a decent life (Jenson and Miller, 2010). This method has some merits over the other food measurement approaches: it measures food consumption directly instead of food availability, reports both dietary quality and calorie intake at individual levels, and recognizes current and longer-term dietary intake patterns (Bashir and Schilizzi, 2012). Maxwell *et al*. (1999) advocated that calorie intake is accounted for as the gold standard measure of food security. However, measurement of food calorie intake using household recall method is time consuming caused by biased results and high operation costs (Hoddinott, 1999).

## 4.3. Methodology

### 4.3.1.Estimating household vulnerability to food insecurity

The following steps are used to identify the food poverty line required to meet the minimum daily dietary energy requirement. First, a basket of food items consisting of nineteen staple food products (cereal and none cereal) grouped under seven food categories consumed in the last 7 days were selected using the Ethiopian food Consumption Table and KII and FGD. The quantity of the basket was determined considered the bundle meets the minimum normative daily dietary requirement *i.e.*, 2,200 kcal per day per AE as a benchmark. The common technique of evaluating calorie intake is using the information of different foods consumed by a household and converting it into calories using a calorie conversion table. Then this basket was valued at local prices and the value of the food poverty line was defined. As a result, the food poverty line for the study area was found to be 35 ETB[2].

This method is analogous to the poverty measurement approach because poverty is defined as a lack of sufficient food to attaining the minimum standard of living. Food insecurity often referred to food poverty due to robust relations between poverty and food insecurity although the causes and effects of each are different (Webb and Rogers, 2003, Sibrian, 2008). However, collecting FEI data is expensive and complex task leads to a high level of measurement error and potential misclassification (Perez-Escamilla *et al.,* 2008). The cost of basic needs (CBN) is an extension of food energy intake except the CBN method embraces an adequate level of non-food items like housing, electricity, water, health, and education (Headey and Ecker, 2013). However, there is no clear cut way to define and exhaustively listed non-food expenditures in developing countries, including Ethiopia (Bellù and Liberati, 2005).

Estimating vulnerability to food insecurity in developing countries is very difficult because there are inadequate panel data at the household level on which the models rely (Capaldo *et al.,* 2010). Panel data offset cross-sectional data because it accounts for the effect of invariant variables over time (Hoddinott and Quisumbing, 2008). Hence, most empirical studies depend on cross-sectional data to estimate a household's vulnerability to food insecurity (Chaudhuri *et al,* 2002). However, cross-sectional data have a drawback to measuring vulnerability because the data is unable to take in household inter-temporal variability. Cross-sectional variance can explain part of the inter-temporal variance due to idiosyncratic shocks, but it will not capture aggregate (household invariant by time-varying) shocks (Holzmann *et al.*, 2003). Tesliuc and Lindert (2002) suggested that robust vulnerability estimation could exist if the distributions of risks and its management measures are similar from one period to another coupled with time-series climate data.

This study applied the methodology proposed by Chaudhuri *et al.* (2002) to estimate the expected and variance of food consumption expenditure using cross-sectional data including long term annual rainfall and temperature data. For a particular household $i$, the vulnerability of a household

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[2] ETB refers to Ethiopian currency Birr. The approximate official exchange rate at the time the study took place was 1US=26.71ETB.

at time $t$ is defined as the probability of its consumption below the food poverty line at time $t+1$ stated as:

$$V_{it} = \Pr(C_{i,t+1} \leq Z) \qquad (4.1)$$

Where $V_{it}$ is the vulnerability of the household's $i$ at time $t$,$C_{i,t+1}$, is a measure of household per capita calorie requirement i.e., 2,200 kcal per AE per day at the time $t_{+1}$ and $Z$, food poverty line threshold level.

Both idiosyncratic and covariant shocks assumed to follow the stochastic process produce the consumption of $i$-th household driven from Vulnerability as Expected Poverty approach. This approach widely applied to measure a household's vulnerability to poverty and food insecurity (Chaudhuri, 2003; Günther and Harttgen, 2009; Capaldo *et al.*, 2010) driving from food expenditure function as:

$$\ln C_i = X_i\beta + \varepsilon_i \qquad (4.2)$$

Where, $C_i$ is the natural $log$ of per capita household consumption expenditure for the $i$-th household, $X_i$ represents a vector of observable household's socioeconomic and natural shocks characteristics, $\beta$ is a vector of coefficients to be estimated, and $\varepsilon_i$ is a disturbance term with mean zero and variance of $\delta^2_{e,i}$ holds the unexplained part of households' food consumption expenditure (idiosyncratic shocks) yields to various per capita consumption expenditure. For estimation of the variance of expected consumption Chaudhuri *et al.*(2002) assuming a fixed $\beta$ because the idiosyncratic shocks to consumption are normally distributed over time for each household and the state of the economy is stable over time ruling out the possibility of common shocks.

Hence, the uncertainty about future consumption related exclusively from the uncertainty about the idiosyncratic shock, $\varepsilon_i$ the household will encounter in the future. Hence, the square of the error term or the unexplained part of per capita household consumption expenditure is regressed on the same observable households' characteristics:

$$\delta^2_{e,i} = X_i\theta + \tau \qquad (4.3)$$

Where θ represents a vector of parameters to be estimated, τ is the vector of residuals of this estimation having all the possible properties of residuals that $\varepsilon_i$ does not exist. The conventional regression analysis using ordinary least squares (OLS) estimation techniques assume homoscedasticity, i.e. the same variance $v(e_i)$=$\delta^2$ across all households$i$. But, Chaudhuri *et al*. (2002) assume that the variance of the error term is not equal across households due to the unequal impact of shocks on consumption hence, the error term is assumed to be heteroscedastic. Using OLS for estimation of β and θ leads to an unbiased but inefficient coefficient (Günther and Harttgen, 2016).

Amemiya (1977) suggested three-step Feasible Generalized Least Squares (FGLS) method when the assumption of minimum variance violates to estimate efficient β and θ results. Therefore, using the estimates $\hat{\beta}$ and $\hat{\theta}$ can be estimated the expected log food consumption and the variance of log food consumption expenditure for each household (Gaiha and Imai 2008), respectively

$$\mathrm{E}(\ln C_i|X_i) = X_i\,\hat{\beta} \qquad\qquad (4.3.1)$$

$$\mathrm{E}(\ln C_i|X_i) = X_i\,\hat{\theta} \qquad\qquad (4.3.2)$$

The food consumption expenditure is log-normally distributed (ln $C_i$ is normally distributed) used to apply these estimates to form an estimate the likelihood a household with the characteristics, $X_i$, will be food insecure shortly (say at time t+1) (Chaudhuri *et al*, 2002). This allows estimating vulnerability to food insecurity or the probability of being food insecure in the future conditional on current consumption expenditure and household characteristics, by:

$$\widehat{V_i} = \hat{P}(lnC_i < lnZ|X_i) = \phi\left(\frac{\ln Z - ln\widehat{C_i}}{\sqrt{\widehat{\delta_i^2}}}\right) \qquad\qquad (4.4)$$

Where $\phi$(.) denotes the cumulative density of the standard normal distribution function, $\hat{\delta}$ is the standard error of the regression; Z is the predetermined threshold food to meet the minimum energy requirement. $\widehat{V_i}$ Denotes the probability that each household falling below the minimum threshold in the future ranges between zero and 1 value.

Classifying household vulnerability according to their food security status is among the primary objective of vulnerability analysis. Hence, if $\widehat{V_i}$ = 0; household $i$ will spend an adequate amount of food for consumption in the future with the certainty that at least the minimum amount of calories required will be obtained, and when $\widehat{V_i}$ =1; household $i$ will consume fewer calories than the suggested threshold. Households are classified as vulnerable if the probability of $V_i$ is greater than or equal to 0.5, and non-vulnerable, otherwise (Chaudhuri *et al.*, 2002). This threshold level of vulnerability was defined for a time horizon of the next year. This implies a household is called vulnerable if the probability of falling below the welfare benchmark (2,200 kilo-calories) utmost once in the next one years is greater than 0.5.

### 4.3.2.Decomposing food insecurity and vulnerability

Adger (2006) employs three measures of vulnerability based on the Foster-Greer-Thorbecke (FGT) framework of poverty measures which satisfy the axioms used to define a robust welfare measure. This vulnerability measure includes headcount vulnerability, vulnerability gap, and vulnerability severity. Generally, the FGT indexes are defined as follows (Foster *et al.*, 1984):

$$V_\alpha = \frac{1}{n}\left[\sum_{i=1}^{q}(w_0 - w_i)/w_o)^\alpha\right] \qquad (4.5)$$

Where, $V_\alpha$ is the measure of vulnerability indicators, $w_i$ is the actual probability of household '$i$' to fall below the food insecurity line of 2200 kilo-calories or 35 EBR per day per AE; $w_0$ is the threshold probability of becoming vulnerable (i.e. 0.5); $n$ is the total number of households; $q$ is the number of households above the vulnerability threshold of 0.5, and $\alpha$ is a measure of sensitivity parameter of the vulnerability index. Three food insecurity indexes are calculated based on three values of$\alpha$. When $\alpha = 0$, $V_\alpha$ is the headcount vulnerability index or the proportion of vulnerable households of the total sample.

Monotonicity, transfer, and focus are the main axioms for a good measure of food consumption (Ravallion and Chen, 2001). However, headcount vulnerability measures violate these three axioms, besides, to fail to show how poor the poor are. When $\alpha$=1, $V_\alpha$ is the vulnerability gap index measures the extent of the distance between a household's actual probability of becoming food insecure and vulnerability thresholds of 0.5. Although the poverty gap measure satisfies the monotonicity axiom it violates the transfer and focuses axiom. When$\alpha = 2$, $V_\alpha$ the measure is vulnerability severity. It satisfies the three axioms that are desirable for food consumption measures.

### 4.3.3. Model variable description

Though most of the independent variables are self-explanatory the definitions of independent variables and hypothesized relation with expected food consumption expenditure presented in this section. Male-headed households expected to have more food consumption expenditure than female-headed households'. Because male-headed households are more fortunate in terms of asset and productive capital ownership in rural Ethiopia. In line with this argument, male-headed households were found food secure in rural South Africa (Tibesigwa and Visser, 2016) whereas their expected food consumption expenditure decreased in Ethiopia (Bogale, 2012).

Household head's age could be influence expected food consumption expenditure via asset creation and technology adoption *inter alia*. Correspondingly, Demeke *et al.* (2011); Bogale (2012) indicated that vulnerability to food insecurity decreased with the head's age in Ethiopia. Education has a vital role to achieve food security through human capital development and acquiring better agricultural technology information. Supporting this argument Habtewold (2018); Demeke *et al.* (2011) showed education directly influences food security status in rural Ethiopia.

A large family size together with an active labor force increased food consumption expenditure but households with a high dependency ratio would decreased expected food consumption expenditure. However, the high dependency ratio may increase expected food consumption expenditure because the dependent family members need limiting per capita food intake compared with the active labor force. Prior empirical studies in Ethiopia showed mixed results regarding the influence of dependency ratio on food security (Bogale and Shimelis 2009; Beyene and Muche, 2010). However, in this study, it is expected that the dependency ratio increase expected food consumption expenditure.

Capaldo *et al.* (2010) analyze vulnerability to food insecurity measured by kilocalorie consumption in rural Nicaragua using FGLS. The result of the analysis indicated among the factors that increased food consumption significantly was education level and share of income from farm sales while household size, distance to the nearest road, and share of income from farming activities were decreased significantly food consumption. Moreover, Bogale (2012) following the same procedure revealed that expected food consumption expenditure was significantly increased with farming land, fertilizer, crop diversification, access to irrigation and land fertility status but consistent with

Capaldo *et al.* (2010) expected food consumption expenditure decreased with household size in Eastern rural Ethiopia. However, Demeke *et al.* (2011) using panel data concluded that large family size increased food consumption in rural Ethiopia due to the availability of labor. Household heads with large family size (AE) have inadequate food access for consumption particularly when they entail a high dependency ratio (Mutabazi *et al.* 2015).

Households with membership community-based organizations have received information about agricultural technologies and share risks between community members that go to increased food consumption expenditure (Bedeke *et al.*, 2019). Women in *Borana*, Southern Ethiopia share food resources using the indigenous social network to smooth household food security during hardship time (Anbacha *et al*., 2018).

Access to credit eases liquidity constraints and improves technology adoption that increased expected food consumption expenditure (Simtowe and Zeller, 2006). Previous empirical studies in Ethiopia indicated that access to credit increased food consumption (Habtewold, 2018). Moreover, livelihood diversification improves food security outcomes in rural Ethiopia (Manlosa *et al.*, 2019). Empirical studies employed rural household panel data concluded that households' that have irrigation potential and sufficient rainfall increased food security in developing countries including Ethiopia (Capaldo *et al.*, 2010; Hunnes, 2015).

Livestock ownership is the sub-components of physical capital expected to influence positively expected food consumption expenditure. Households with large livestock are useful as a buffer stock to protect consumption fluctuations during climate extremes (Li *et al.*, 2017). Households' geographical location correlates with rainfall and the major determinants of food-security status in rural Ethiopia (Hunnes, 2015). Demeke and Zeller (2012) indicate that rainfall shock is an important factor affecting households' food security over time in rural Ethiopia.

## 4.4.Result and Discussion

### 4.4.1.Sample household characteristics

Tables 4.1 represents the summary statistics of variables expected to influence mean and variance food consumption expenditure. The minimum food consumption expenditure per AE per day threshold was estimated to be EBR 35 (natural log35~3.56). The mean log food consumption expenditure is below the cutoff level to attain food security. The Sen's slope estimator showed that annual rainfall trends in all kebeles were decreased for analysis with different magnitude.

Table 4.1 Definition of variables and summary statistics

| Variable | Description | Mean | SD | Exp.sig |
|---|---|---|---|---|
| ln(conexp) | Natural log of food consumption expenditure in ADE (EBR) | 2.867 | 0.513 | --- |
| Sex | Dummy of HH (male= 1, 0 otherwise) | 0.77 | 0.42 | + |
| Age | Age of the HH in years | 52.4 | 12.27 | + |
| Education | The education level of HH in school (years) | 2.26 | 2.98 | + |
| Dependency | Age below 15 and above 65 to age between 15-65 (ratio) | 0.91 | 0.86 | + |
| Family size | Total number of a family member in AE | 4.59 | 1.70 | - |
| Social network | Number of a community-based organization (unit) | 1.41 | 1.53 | + |
| Credit | Dummy for access to credit (yes = 1, 0 otherwise ) | 44.69 | 0.49 | + |
| Livelihood diversification | The *inverse* of the number of agricultural livelihood activities +1 | 0.86 | 0.24 | + |
| Road | Average walking distance to the nearest motor roads (min) | 30.53 | 35.02 | + |
| Farm size | Total cultivated land holding (*tsimad*) | 1.30 | 0.77 | + |
| Livestock | Livestock holding (TLU) | 2.65 | 1.74 | + |
| Fertilizer | Amount of fertilizer used (quintal) | 0.56 | 0.43 | + |
| Improve seed | Amount of improved seed uses (Kg) | 9.20 | 20.96 | + |
| Irrigation potential | Share of irrigable land to total area (*tsimad*) | 0.28 | 0.11 | + |
| Malaria exposure | months exposure to malaria*owning at least one bed net (range: 0-12) | 1.01 | 0.84 | - |
| Flood | Cultivated land damaged by flood last ten years (*tsimad*) | 0.20 | 0.38 | - |
| Livestock death | Livestock death in the last ten years | 2.86 | 4.62 | - |
| Energy | Monthly energy expenditure (EBR) | 111.65 | 325.85 | + |
| Rf-Alitena | Rainfall trend in Alitena (mm) | -11.29 |  | - |
| Rf _Hareza | Rainfall trend in Hareza (mm) | -9.96 |  | - |
| Rf _Selam | Rainfall trend in Selam (mm) | -3.82 |  | + |
| Rf _Degamba | Rainfall trend in Degamba (mm) | -5.17 |  | + |

Table 4.2 presents food security FGT measurement indices decomposed in the two Districts. The result revealed that considering the food security threshold of 2,200 kilo-calories, about 82 percent and 87 percent of households in Hawzen and Irob districts were food insecure. Of which Hawzen and Irob had 56 percent and 44 percent relative contribution to the total 84 percent of household food insecurity in the study area respectively. This implies that the prevalence of food insecurity is very high in both districts. Weldearegay and Tedla (2018) found 84.3 percent of households were food insecure in Central Tigray rural Ethiopia congruent to this study.

The food-insecurity gap of 0.42 and 0.58 suggested that at least 42 percent and 58 percent of an increase in mean food consumption expenditure is required to achieve households' food-secure in Hawzen and Irob districts, respectively. An equivalent 49 percent rise in mean food consumption expenditure was essential to lift all the households from food insecurity. Similarly, Asmamaw *et al.* (2015) reported that 60 percent and 41 percent of the depth and severity of food insecurity in the Amhara Region, Ethiopia.

Table 4.2 Decomposition of food security status

| | Current food-insecurity | | | Vulnerability to food insecurity | | |
|---|---|---|---|---|---|---|
| FGT index | Hawzen | Irob | Total | Hawzen | Irob | Total |
| Headcount food insecure | 0.823 | 0.867 | 0.841 | | | |
| Relative contribution (percent) | 56 | 44 | 100 | | | |
| Gap food insecurity | 0.42 | 0.58 | 0.49 | 0.78 | 0.76 | 0.77 |
| Relative contribution (percent) | 50 | 50 | 100 | 58.2 | 41.8 | 100 |
| Severity of food insecurity | 0.235 | 0.395 | 0.30 | 0.614 | 0.575 | 0.59 |
| Relative contribution (percent) | 44 | 56 | 100 | 58.9 | 41.1 | 100 |

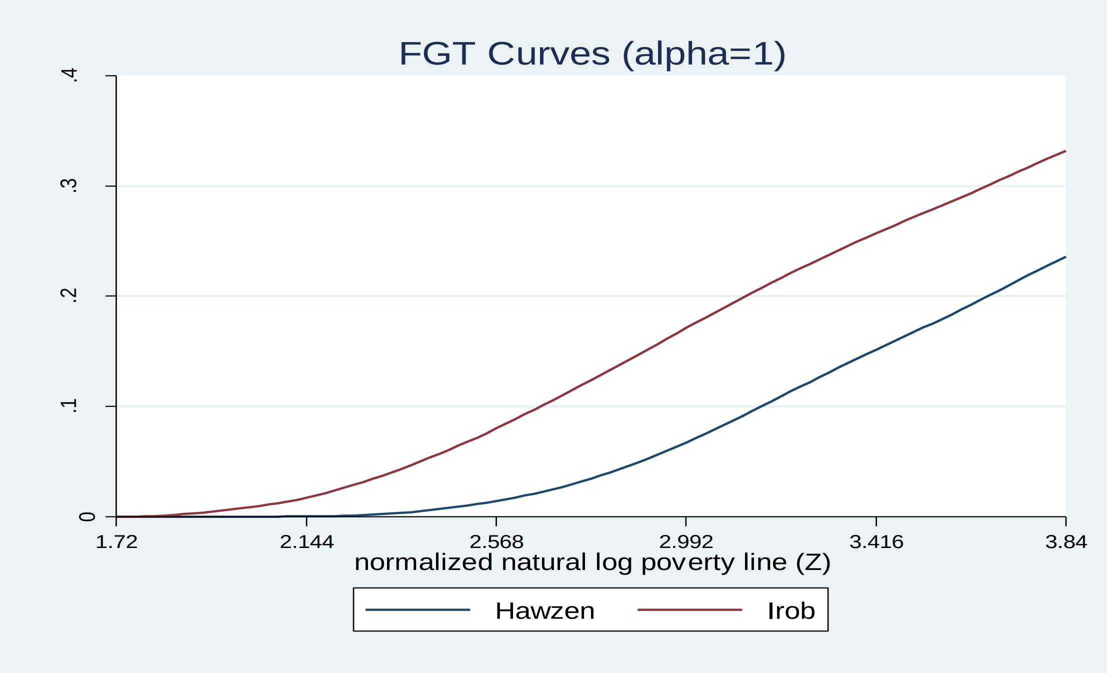

Figure 4.1 Food insecurity curves

Table 4.3 reported that nearly 78.5 percent of the total households were categorized as food insecure for the next year hence considered as chronic food insecure households. Moreover, about 7 percent of the total households were considered as transitory food insecurity (short-term and temporary) they were less likely from a sudden drop into food insecurity in the next one year and escape from food insecurity. Furthermore, about 15 percent of the total households were under the transient food security categorized (seasonal food security) they have a high probability of being food insecure shortly *i.e.,* next year. The result showed that nearly 1 percent of households had fairly stable food security levels. Generally, about 22 percent of the total households (7.11 and 14.8 percent) had an unstable food insecurity status. Overall, the number of households' becoming food insecure soon is more than those households are currently food insecure. Poor people become less vulnerable if they live in relatively stable contexts but non-poor people can be vulnerable if they live in unstable contexts (Ellis, 2003).

Table 4.3 Classification and decomposition by vulnerability and food security status

| Vulnerability status | Food security status | | | | | |
|---|---|---|---|---|---|---|
| | Food insecure | | Food secure | | Total | |
| | No. | Percent | No. | Percent | No. | Percent |
| High Vulnerability ($V_i \geq 0.5$) | 281 | 78.49 | 53 | 14.8 | 334 | 93.29 |
| Low Vulnerability ($V_i < 0.5$) | 20 | 7.11 | 4 | 1.12 | 24 | 6.71 |
| Total | 301 | 84.1 | 57 | 15.90 | 358 | 100 |

### 4.4.2. Econometrics model results

The model results showed overall fit with significant *F* statistics *F*(21,336) =11.52, P<0.01) indicating that the expected food consumption expenditure is strongly related to the independent variables. The multicollinearity problem was tested using the Variance Inflation Factor (VIF) and Contingency Coefficient for continuous and dummy variables, respectively. Based on the VIF (Xi), the data has no serious multicollinearity problem with a mean VIF value of 1.93 and for each independent variable, the value of VIF is less than 10 (*Annex* 1.9 and 1.10). As a rule of thumb VIF and Contingency Coefficient values exceeds 10 and 0.75 indicating there is no linear correlation among the independent variables, respectively (Healy, 1984; Gujarati, 2009). Moreover, about 42 percent of the expected food consumption expenditure was explained by the independent variables.

Out of the total nineteen independent variables 8 variables were significantly influencing household's expected food consumption expenditure (Table 4.4). The empirical results showed that future food consumption expenditure was increasing with dependency ratio, livestock size, irrigation potential, livestock death, energy cost, and positive rainfall trend in *Degamba Kebele* whereas consumption expenditure was decreasing with family size and negative rainfall trend in *Alitena Kebele*.

The expected food consumption expenditure was increased with the dependency ratio (P<0.01). Garrett and Ruel (1999) suggested that households with more children and elderly have fewer numbers of AE then these individuals have lower-calorie requirements than young adults. As a result, food consumption expenditure is attained among those households with few adults-equivalents. This result was in line with Christiaensen and Boisvert (2000); Azeem *et al.* (2016) found expected food consumption expenditure was significantly increased with the dependency ratio in rural Mali and Pakistan respectively. Moreover, Sileshi *et al.* (2019) reported an increased but insignificant relationship between expected food consumption and dependency ratio in rural Ethiopia.

However, the result of the analysis indicated that expected food consumption expenditure was decreased with family size ($P < 0.01$). This implies that future food consumption expenditure was decreased with family size. A unit increase in family size would decrease the expected food consumption expenditure by about 14 percent, other things remain constant. Moreover, Bogale (2012); Sileshi *et al.* (2019) using FGLS found consistent results from Eastern rural Ethiopia. Moreover, empirical studies from developing countries reported an indirect relation between future food consumption and large family size (Capaldo *et al.*, 2010; Sricharoen, 2011; Azeem *et al.*, 2016).

The result of the model revealed that the expected food consumption expenditure was increased with livestock holding measured in TLU ($P < 0.1$). A unit increase in livestock would increase the expected food consumption expenditure by about 2.6 percent, other things remain constant. In line with the prior expectation, Demeke *et al.* (2011) ascertained that as the number of livestock owned increases vulnerability to food insecurity decreased. Because, households with large livestock sizes have higher net income from selling animal products thereby increased future food consumption expenditure (Wainaina *et al.*, 2016; Mekuyie *et al.*, 2018).

Moreover, the analysis of the result revealed that expected food consumption expenditure was increased with livestock death ($P<0.05$). This is a strange result but often livestock death caused by drought reduces the burden on open grazing land subsequently leads to higher expected prices in the successive periods due to local supply shortages ultimately increased future expected food consumption expenditure(Kazianga and Udry, 2006).

Similarly, the expected food consumption expenditure was increased with irrigation potential ($P<0.05$). A unit increase in irrigation would increase the expected food consumption expenditure by about 45 percent, other things remain constant. Access to irrigation improves expected food consumption expenditure through increased crop production, diversification, and technology adaptation during thereby increased food consumption stability (Balana *et al.,* 2019). This result is consistent with Tesfaye *et al*. (2008); Bogale (2012) reported expected food consumption expenditure increased with irrigation access in rural Ethiopia. The expected food consumption expenditure was increased with the monthly energy cost ($P<0.01$). In the study area, about 16 percent and 12 percent of households were used electricity and kerosene for light and cooking purposes in conjunction with the traditional source of energy mostly located adjacent to the urban periphery.

The expected food consumption expenditure was decreased with a negative annual rainfall trend in *Alitena* Kebele District ($P>0.05$). This indicated that future expected food consumption expenditure negatively influenced by a decreased annual rainfall amount. Consistently, Generoso (2015) found inter-annual and seasonal rainfall variability has a negative influence on food consumption in rural Mali. Moreover, Ervin and Gayoso de Ervin (2019) indicated that decreased annual rainfall negatively affected food caloric consumption and food consumption in rural Paraguay.

However, the result of the model indicated that expected food consumption expenditure was increased with an annual rainfall trend in *Degamba* Kebele ($P<0.05$). *Degamba* was located in Hawzen District where during the main rainy season rainfall was increasing (Table 2.6) indicated no circumstances of agricultural drought. Gao and Mills (2018) concluded that increasing rainfall positively influence food consumption in rural Ethiopia. Moreover, Lewis (2017) suggested that rainfall variability is not necessarily a primary driver of variation in total food availability rather its correlation with individual crop production is important in Ethiopia.

Table 4.4 Three-step FGLS results for determinants of vulnerability to food insecurity (n=358)

| Variables | log food consumption expenditure | | Variance of food consumption expenditure | |
|---|---|---|---|---|
| | Coef. | Robust Std. Err. | Coef. | Robust Std. Err. |
| Sex | 0.0251 | 0.0633 | 0.0244 | 0.0338 |
| Age | 0.0014 | 0.0022 | -0.0007 | 0.0011 |
| Education | 0.0078 | 0.0086 | -0.0055 | 0.0043 |
| Dependency | 0.0738*** | 0.0251 | -0.0109 | 0.0124 |
| Family size | -0.1399*** | 0.0140 | -0.0193*** | 0.0072 |
| Social network | 0.0096 | 0.0165 | 0.0088 | 0.0080 |
| Credit | 0.0383 | 0.0440 | 0.0071 | 0.0232 |
| Livelihood div | 0.0093 | 0.0951 | 0.1430*** | 0.0485 |
| Road | 0.0004 | 0.0005 | 0.0001 | 0.0004 |
| Farm size | 0.0400 | 0.0454 | 0.0150 | 0.0220 |
| Livestock | 0.0255* | 0.0154 | -0.0062 | 0.0075 |
| Fertilizer | 0.0859 | 0.0784 | 0.0112 | 0.0386 |
| Improve seed | 0.0010 | 0.0011 | -0.0002 | 0.0006 |
| Irrigation potential | 0.4568** | 0.1959 | -0.1609 | 0.1002 |
| Malaria exposure | -0.0155 | 0.0275 | 0.0017 | 0.0134 |
| Flood | 0.0177 | 0.0586 | -0.0152 | 0.0289 |
| Livestock death | 0.0134** | 0.0057 | -0.0002 | 0.0028 |
| Energy | 0.0002*** | 0.0001 | -0.0001** | 0.0001 |
| Rf-Alitena | -0.1723** | 0.0848 | 0.0336 | 0.0374 |
| Rf _Degamba | 0.2432** | 0.1171 | -0.0588 | 0.0526 |
| Rf _Selam | 0.0708 | 0.1192 | -0.0444 | 0.0535 |
| Constant | 2.7769*** | 0.1678 | 0.4119*** | 0.0898 |
| F (21,336) | 11.52 | | 1.45 | |
| Prob > F | 0.00 | | 0.09 | |
| R-square | 0.4186 | | 0.083 | |
| Root MSE | 0.3676 | | 0.026 | |

***, **, and * significance level at P<0.01, P<0.05 and P<0.1 respectively

## 4.5.Conclusion and recommendations

In Ethiopia achieving stable food security is among the top objective of the development policies. However, prolonged chronic food insecurity and pervasive vulnerability have remained the main features of the country. Therefore, the main objective of this study was to analyze households' vulnerability to food insecurity unlike the convectional ex-post food security status using vulnerability as expected poverty framework and FGT decomposition method. The local food poverty line was defined using the least cost method to measure the probability at which each household's will fall below this line keeping their characteristics and idiosyncratic and covariant shocks.

Holding the food poverty line the results revealed that about 84 percent and 93 percent of the total households suffered from current and future food insecurity in the study area, respectively. When households categorized into current and future food security status about 78.5 percent considered chronic food insecurity, 7 percent under transient food insecurity, and about 15 percent under transient food security but only 1 percent of households have stable food security, respectively. Future food consumption expenditure was increased with dependency ratio, livestock size, irrigation potential, livestock death, energy cost, and positive rainfall trend in *Degamba Kebele* whereas decreased with family size and negative rainfall trend in *Alitena Kebele*.

The above empirical results help to provide the following policy recommendations. First, local government policy emphasis should be not only the current food insecurity but also on those households more likely to be food insecurity shortly through long term corresponding programs such as PNSP-HABP (household asset-building program) to tackle food consumption fluctuation. Second, large family size depress expected food consumption expenditure hence, reinforcement of the rural family planning program is crucial to achieving the minimum food poverty line. Moreover, harmonizing the current dependency ratio with expected implemented family planning measures to supply enough labor force for the agriculture sector. Third, households with better irrigation potential have a paramount significant positive influence on expected food consumption expenditure. Therefore, local government should revitalization and boost investment in small scale irrigation schemes to supplemental irrigation. Lastly, strengthen integrated watershed management in conjunction with agriculture water management should be among the top policy interventions in *Alitena* kebele to supplement the frequent rainfall shortfalls.

# 5. Household's coping strategies for climatic shocks

## *Abstract*

*Households employ different risk coping strategies to avoid food consumption fluctuation but a substantial gap has been remained to understand the functions of local institutional arrangements to address adverse shocks. Therefore, the main objective of this study is to examine the factors that determine a household's decision to choose the different risk-coping institutional arrangements. A multi-stage sampling technique was employed to select 358 households randomly coupled with Gridded annual rainfall data during 1983-2015. Substitutability among the institutional arrangements was revealed by the negative pair-wise correlation matrix of the model. Moreover, the multivariate probit model results show that the likelihood of a household's decisions to choose the different risk coping strategies is unique and the factors that determine are different. The model results indicated that male-headed households, access to credit, motor road, and market, membership in community-based health insurance, TV/radio ownership, and annual rainfall in Irob statistically enhanced the choice of climate change risk coping strategies. Thus, capitalizing the interdependence functions of rural institutional arrangements is essential to increase households' risk coping capacities against adverse shocks. Furthermore, strengthen intra-household ties and reciprocity relations with other households through facilitating family cooperation to foster risk coping strategies.*

**Keywords**: Institution, coping, idiosyncratic, shocks, MVP model.

## 5.1. Introduction

Poor rural households in developing countries have faced massive uncertainties and constraints ranging from extreme weather events to market imperfections. As a result, food consumption fluctuation is the primary formidable challenge households experienced due to these climatic and non-climatic challenges (Hoddinott and Quisumbing, 2010). Unfortunately, these households are less protected against adverse shocks since insurance and credit markets are imperfect due to supply constraints and higher transaction costs (Visser *et al*., 2019). Often, in the absence of formal institutions, households smooth income, and consumption variability through implementing various alternative mechanisms to deal with risks (Jaramillo *et al*., 2015). For instance, smallholder farmers in East Africa commonly used several local coping strategies through indigenous knowledge to develop their resilience and adaptive capacity (Mubiru *et al.*, 2018).

Formal institutional arrangements risk coping mechanisms are like market-based insurances that support to combat spatially covariate shocks (Agrawal, 2008). Whereas, informal risk coping mechanisms employed by local communities to cope with climate change when the former mechanisms are absent or inefficient including self-insurance, informal networks-based risk-sharing, and inter-temporal consumption smoothing (Yang, 2010). Empirical evidence in Ethiopia revealed that poor households employed both formal and informal insurance arrangements in response to the risk that threatening their livelihood sources (Dercon, 2002; Murendo *et al*., 2011). Moreover, Berhanu (2002) advocated that in Ethiopia informal insurance arrangements have a paramount benefit through providing help during idiosyncratic shocks.

Several empirical evidences have been suggested that households in developing countries, as elsewhere in the world, use a range of response mechanisms to deal with extreme weather events (Fafchamps, 2009; Jaramillo *et al*., 2015; Alemayehu and Bewket, 2017; Mubiru *et al.,* 2018). Contrarily, Nhemachena and Hassan (2007) overlooked these risk coping and adaptation strategies, indeed, considered farmers as '*dumb-economic agents'* who do not respond to climate change. In reality, households apply different coping mechanisms to mitigate the effect of extreme weather events and climate variability and smooth income and consumption fluctuations (Dercon *et al*., 2008). This implies household’s is not a simple victim receivers of external negative shocks.

Recently, studies provide special attention for rural institutional arrangements, such as informal insurance networks as risk coping mechanisms to smooth consumption fluctuation during crises. In rural northern Tanzania reduced food consumption and increased casual employment are among the main coping strategies to smoothing consumption (Trærup and Mertz, 2011). Moreover, social networks are served as a crucial source of information for technology adoption in developing countries (Conley and Udry, 2010). Foster and Rosenzweig (2001); Fafchamps and Lund (2001) revealed that mutual credit provides an intensified help to share risk among members of the same community.

Dercon *et al*. (2008) emphasized the functions of *Iddir* a form of societies' collective action to mitigate idiosyncratic shocks though it has limited capacity to respond for covariate shocks in most rural Ethiopia. Moreover, Aredo (2010) indicated that *Iddir* is a form of social capital widely used informal insurance arrangement for risk-pooling and risk-sharing mechanisms in rural and urban Ethiopia. The main challenge facing social network risk pooling includes imperfect information, resource constraints, and limited capacity to address spatially covariant shocks (Günther and Harttgen, 2009).

When spatially covariant shock occurs, informal risk coping mechanism may not absorb income and consumption fluctuations successfully. Therefore, the combined functions of rural institutions to manage extreme weather events have got a paramount interest in developing countries (Anderson, 2003; Holzmann *et al*., 2003; Bisaro *et al*., 2017). Particularly, in SSA public institution has a vital function in adopting climate change adaptation strategies (Zewde and Pausewang, 2002). Household consumption smooth is unlikely to depend on a specific asset portfolio, rather it requires a combination of multiple institutional arrangements to address risks effectively. Because relying on a single risk coping strategy is inadequate to address the highly complex, dynamic, and uncertain risk (Boansi *et al*., 2017). As a result, rural households largely implement a blend of multiple rural institutional arrangements as insurance mechanisms to cope with risks effectively (Holzmann, 2003; Fafchamps, 2009; Adimassu and Kessler, 2016).

Rural institutions provide crucial support to promote adaptation and coping strategies to climate change by providing external resources (Agrawal, 2008; Moser and Ekstrom, 2010). Furthermore, institutions have significant influence through determining the direction and magnitude of resource flow to different social groups (Agrawal and Perrin, 2009). Despite, few studies have revealed the role of local institutions yet little is known about the complementarities and substitutability existed among the various institutional arrangements used to moderate climate change impacts (Wong *et al.,* 2014). Consequently, in many developing countries including Ethiopia determining a successful risk-coping strategy is the major challenge for human development achievements (Demeke and Zeller, 2012).

Likewise, in Ethiopia, rural household's adaptation and risk coping strategies to climate change and variability have been widely studied (Rahmato, 1991; Deressa *et al.,* 2009; Alemayehu and Bewket, 2017; Adimassu and Kessler, 2016; Yohannes *et al*., 2017), among others. Nonetheless, there have been growing empirical studies in this regard, little is known regarding the function of rural institutional arrangements and characteristics needed in protecting household food consumption fluctuation by extreme climatic stress. Therefore, against the above backdrops, the main objective of this study is twofold: analyzed the factors determining household's choice among the existed risk coping strategies and identify the complementarities and substitutability among the risk coping strategies applied during extreme climate shocks.

## 5.2. Household risk coping strategies and the role of rural institutions

Adaptation mainly differ from coping according to the temporal reference at which it happens (Fischer, 2019). Coping strategies are short term and unplanned activities take place within the existing structure in response to unexpected negative impacts while adaptation strategies are long-term and planned actions to respond to the expected stresses changing the framework within which coping takes place (Smit and Wandel 2006; Alemayehu and Bewket, 2017). Households employed different risk coping strategies to reduce the impacts of adverse shocks then followed by a return to the previous practices (Trærup and Mertz, 2011). Both strategies are essentially related implies that reinforcing coping strategies is a prerequisite for facilitating adaptation, in that way reducing the need for additional coping strategies (Eriksen *et al.,* 2005). The capacity of households to deal with risks depends on the characteristics of risks face and the size of assets household's owned (Rashid *et al.,* 2006).

In developing countries, where financial markets are absent or imperfect households will shift into informal arrangements include self-insurance through precautionary savings and informal group-based risk-sharing to protect consumption fluctuation (Fafchamps, 2009; Jaramillo *et al*., 2015).

Informal insurance group based networks help as a substitute for market-purchased insurance (Park, 2006). For instance, Abid *et al. (*2015) found that social networks are crucial mechanisms to influence farmers' adaptation decisions to address climate change impacts. Murendo *et al*. (2011) concluded that in rural Ethiopia households employed an *ex-post* risk coping strategy through informal networks during drought impacts. In line to this finding, Dercon (2002) revealed that household food consumption adjustment and informal community networks are commonly practiced in rural Ethiopia to protect consumption decline. Moreover, Caeyers and Dercon (2012) underlined that almost all households in Ethiopia have a network that can provide support during shock periods. Such as, *Iddir* is an informal insurance arrangement often employ in Ethiopia to pool and share risks when households have deprived access to formal market arrangements to reduce idiosyncratic shocks (Aredo, 2010).

A fundamental argument in the coping literature is the notion that coping strategies have a visible sequence that corresponds to an increasing level of distress. Austerity, reduced food consumption, temporary migration, divestment and asset disposal, and crisis migration is the apparent sequential series of survival strategies during the 1984 famine period in Wollo, northern Ethiopia (Rahmato, 1991). Hence, household's risk coping strategies decision is not haphazard and instantaneously rather based emanated from past experiences and resources availability. However, the effectiveness of informal arrangements has been often inadequate to overcome larger covariate shocks, and the presence of social exclusions (Günther and Harttgen, 2009).

Market-based arrangements also referred to formal financial institutions that increased the capacity of households to manage risk using physical, financial, and human assets. However, information asymmetry and social exclusion from financial services worsened the persistent market failures in developing countries (Holzmann *et al.*, 2003). Consequently, financial institutions are incapable to provide financial services for the extreme poor households because of insurance and credit markets are underdeveloped or do not exist at all. Therefore, the credit-constrained poor household's substituted market-based arrangements with informal arrangements to deal with adverse shocks (Holzmann, 2001). Indeed, rich households have been got microcredit loans mostly from rural microfinance institutions (MFI). However, Dercon (2002) suggested that self-insurance is an inefficient strategy during the common shock that leads to asset prices decline since households respond to those shocks in a similar vein. For instance, the purchasing power of assets was dropped by two-thirds during the 1984/85 famine period in Ethiopia (Dercon, 2002).

When the former two risk coping institutional arrangements do not exist or remain inefficient public arrangement can provide social insurance and transfer payments programs to reduce risks. This includes government support, social programs, and unemployment benefits. However, in many developing countries, public safety-nets are underdeveloped due to supply-side constraints (Delacote, 2009). The government of Ethiopia introduced the PSNP in January 2005 to smooth food consumption and promote livelihood outcomes during the lean seasons thereby protect them from losing their assets and becoming poor (Shigute *et al*., 2017). The program involves 80 percent of public works (food-for-work or cash-for-work) and 20 percent unconditional transfers for those unable to work (Porter and Goyal, 2016). Between 2013 and 2014 the program had about 6 million food insecure individual beneficiaries (Gebrekidan *et al.,* 2019).

Risk-reducing strategies categorized into risk management and risk-coping strategies (Dercon, 2002). The former is an *ex-ante* (income smoothing) strategy that reduce risks by joining weakly correlated returns before the shock occurred. While the latter focuses on reduce risks after it has occurred using real asset sales, dissaving, borrowing, and public and private income transfers to smoothing consumption. This strategy is passive or depleting strategies since it entails future costs associated with the preservation of chronic poverty (Kessy, 2004; Cleaver, 2005). The *ex-ante* risk coping strategy inhabiting agricultural specialization, hinder agricultural technology, hampering economic efficiency finally caused a decline in production efficiency and income (Yang, 2010).

Idiosyncratic shocks are uncorrelated shocks that only affect a relatively small number of a community at different times such as injury, illness, mortality, unemployment, crime, and divorce (Günther and Harttgen, 2009). Spatially covariant shocks are shocks that affect most of the people in a community at the same time such as floods and drought. Idiosyncratic shocks have a high inter-household variance that can insurable in formal and informal financial markets (Wainwright and Newman, 2011). But spatially covariant shocks have low inter- household variance and affect households' welfare status in different degrees at the same time. Hence, covariant shocks are not-insurable in a formal way, rather it demands extensive public arrangements like PSNP (Løvendal and Knowles, 2007).

Risk coping strategies are subject to economic costs, which reduce the adverse impact of shocks during lean seasons, but at the expense of compromising the average productivity and profitability of farmers (Anderson, 2003). Because, households allocate resources to low-risk and low-return activities that are income skewing activities than diversifying their income to manage risks (Dercon, 2002). Trærup and Mertz (2011) understood that households protect short-term consumption, but in the long term, shocks have consequences for low-income households

## 5.3. Methodology

### 5.3.1.Empirical Model specification

Farmers employed multiple adaptation and coping strategies simultaneously to impede negative climate change impacts (Mulwa *et al.,* 2017). The Multivariate Probit (MVP) regression model is robust to estimates the influence of exogenous factors to choose the various strategies simultaneously while permitting the error terms of each of these strategies to be freely correlated (Greene, 2012). Ashford and Sowden (1970) were the pioneers to suggest MVP to model the dependence combination of particular diseases. However, the univariate probit models disregard the likely correlation existed among the unobserved disturbances in the regression equations and the relation between the different implemented strategies. The MVP regression model is a widely applied method in various empirical studies for analyzing correlated dichotomous data set (Adimassu and Kessler, 2016; Mehar *et al*., 2016 Mulwa *et al*.,2017; Asfaw *et al.,* 2019; Bedeke *et al*., 2018). Failing to correct these interrelations leads to biased estimates (Kassie *et al.,* 2013).

The households surveyed in the study area reported that they adopt more than one rural arrangements risk coping strategies simultaneously (Table 5.1). This, prohibits utilizing MNL for the analysis since it assumes the independence of the categories i.e., household choices are mutually exclusive (Greene, 2012). MVP regression relaxes the assumption of the independence of the irrelevant alternatives (IIA) which are assumed by binary and MNL (Green, 2012). Therefore, MVP is suitable for deciding multiple choices at a point in time where the dependent choice variables are multiple probability outcomes with a joint probability of occurrences (Rashid *et al.,* 2006).

Therefore, this study employed an MVP regression model because the three dependent variables are mutually inclusive, this means households could choose more than one climate risk coping strategy. The null hypothesis constructed there is no significant difference in the choice of a risk coping strategy based on the socio-demographic and economic characteristics of households. Thus, the MVP regression model is explained by a set of binary dependent variables to test the hypothesis as follows:

$$Y_{ij} = X'_{ij}\beta_j + \varepsilon_{ij} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (4)$$

Where $Y_{ij}$(j=1, 2, 3) representing the three risk coping strategies employed by the households' [$Y_{i1}$ =1, if the farmer decides to opt for informal arrangements (0 otherwise). $Y_{i2}$ =1 if the farmer decides to opt for market-based institutional arrangements (0 otherwise).$Y_{i3}$ =1if the farmer decides to opt public institutional arrangements (0 otherwise)] used by the $i$th farmer ($i$= 1,..., 358). $X'_{ij}$ is a 1 x $k$ vector of observed variables that affect the choice and decision of the households; $\beta_j$ is a $k$ x 1 vector of unknown parameters (to be estimated), and $\varepsilon_{ij}$ is the unobserved error term. Error terms have a standard normal distribution with mean vector zero and a covariance matrix with diagonal elements equal to 1.

The unknown parameters in equation 1 estimated based on the simulated maximum likelihood (SML) method using the Geweke-Hajivassilion-Keane (GHK) smooth recursive conditioning simulator which draws upon the product of sequentially conditioned univariate normal distribution functions with joint probability. The main rural institutional arrangements as risk coping strategies are informal, market-based, and public arrangements considered as outcome variables in MVP model analysis.

### 5.3.2. Model variables description

Farmers' risk coping strategies to climate changes affected by demographic, socioeconomic, and climatic variables which are often site and household-specific due to diverse conditions (Trærup and Mertz, 2011). Female-headed households have faced a systematic bias that may undermine their competitiveness in the market-based institutional arrangements (Ndiritu *et al.*, 2014). Female-headed households are less likely to receive access to extension services than their male counterparts (Ragasa *et al.*, 2013). Credit access eases liquidity constraints, thus increasing technology adoption, thereby encouraging households to opt for market institutional arrangements (Simtowe and Zeller, 2006).

Households with large farmland have higher economies of scale and production thereby encourage to rely on market-based institutional arrangements as a risk coping strategies (Dercon *et al.*, 2014;

Mulwa *et al.,* 2017). Livestock is an indicator of wealth in the rural area thus households with a more TLU relay on market-based arrangements risk coping strategy during hardship (Gebrekidan *et al.,* 2019). However, catastrophic drought cause destocking due to livestock death or low fertility eventually undermined households' self-insurance capacity (Dercon, 2002). Irrigation reduces agricultural vulnerability to climate shocks hence households with access to irrigation reduce dependency on public arrangement institutional arrangements (Singh *et al*., 2019).

Access to radio disseminates information that facilitates new technology adoption and inputs thereby fosters crop- productivity. As a result, households with access to radio or television are less likely to depend on public institution arrangements to smooth consumption (Ragasa *et al*., 2013). Extreme weather and non-climate change events such as illness and drought negatively affect food consumption levels that required public arrangement intervention (Dercon *et al.,* 2005). Households who lived in high rainfall variability faced more adverse shocks than their counterparts encourage to decided public institutional arrangement risk coping strategy (Træerup and Mertz, 2011).

## 5.4. Result and Discussion

### 5.4.1. Sample household characteristics

The descriptive statistics of the dependent and independent variables used to estimate the MVP regression model was presented in Table 5.1. All the dependent variables are binary, but the independent variables are either dummy or continuous numbers. Households can employ various risk coping strategies depend on the sources, correlation, frequency, and intensity of risks (Holzmann *et al*., 2003). Specifically, 75 percent of households employed public institutional arrangements while 61 percent and 26 percent of households opted for informal and market-based arrangements to smooth food consumption during adverse events, respectively. On average about 40 percent of households owned TV/radio then moderate the imperfect information prevail in rural area. Rural households experienced on average 4 years of drought over the previous ten years besides 25 percent of households reported serious illness in the same period.

Table 5.1 Definition of variables and summery statistics (n = 358)

| Variable | Description | Mean | SD |
|---|---|---|---|
| *Dependent variables* | | | |
| Informal arrangements | Dummy =1 if households choose informal institutional risk coping strategy, 0 otherwise | 0.61 | 0.49 |
| Market arrangements | Dummy =1 if households choose market institutional risk coping strategy, 0 otherwise | 0.26 | 0.44 |
| Public arrangements | Dummy =1 if households choose public risk coping strategy, 0 otherwise | 0.75 | 0.44 |
| *Independent variables* | | | |
| Sex | Dummy of HH (male=1, 0 otherwise) | 0.77 | 0.42 |
| Age | Age of HH in years | 52.4 | 12.27 |
| Family size | Total number of a family member in AE | 4.59 | 1.70 |
| Credit | Dummy for access to credit (yes=1, 0 otherwise) | 44.69 | 0.49 |
| Lnroad | Natural log of walking distance to the nearest motor roads (min) | 2.84 | 1.27 |
| Farm size | Size of cultivated land (*tsimad*) | 1.30 | 0.77 |
| Market | Distance to input-output market ( min) | 52.48 | 69.87 |
| Livestock | Livestock ownership (TLU) | 2.65 | 1.74 |
| Irrigation potential | Share of irrigable land to total area (*tsimad*) | 0.28 | 0.11 |
| CBHI | Member of community-based health insurance (1=yes) | 0.75 | 0.43 |
| TV/Radio | Percentage of households owned TV/radio | 0.39 | 0.49 |
| Drought | Frequency of droughts last 10 years | 3.77 | 3.68 |
| Illness | Percentage of serious illness last 10 years | 0.25 | 0.44 |
| Rf_Ali | Rainfall trend in Alitena (mm) | -11.29 | |
| Rf_Har | Rainfall trend in Hareza (mm) | -9.96 | |
| Rf_SEL | Rainfall trend in Selam (mm) | -3.82 | |
| Rf_Deg | Rainfall trend in Degamba(mm) | -5.17 | |

Table 5.2 reports both idiosyncratic and covariant shocks farmers experienced. Overall, except theft or banditry shocks in Irob district all the households experienced at least one type of shocks over the past ten years. The three worst climatic shocks households experienced over the previous ten years are drought 70 percent, livestock death 60 percent, and flood 44 percent, respectively statistically significant at (P<0.01) corresponding with FGD results. When shocks are disaggregated by the nature of shocks drought, increase agricultural input price, serious illness, and crisis migration is reported as the most adverse shocks experienced by households. Crime shocks were the least shocks households experienced over the past decade. Drought, death of the household head, and illness were the worst shock observed in rural Ethiopia between 1999 and 2004 (Dercon, 2002).

Table 5.2 Extreme adverse shocks faced by households

| Most commonly shocks | Percent* | | | $\chi^2$-value |
|---|---|---|---|---|
| | All | Hawzen | Irob | |
| Climatic shock | | | | |
| Drought | 70.11 | 50.48 | 97.33 | 91.295*** |
| Death of livestock | 60.06 | 41.83 | 85.33 | 68.765*** |
| Flood | 43.58 | 15.38 | 82.66 | 160.458*** |
| Land slide | 17.60 | 7.69 | 31.33 | 33.589*** |
| Economic shocks | | | | |
| Increase agricultural input price | 40.78 | 60.69 | 14.00 | 76.679*** |
| Property damage | 3.63 | 3.85 | 3.33 | 0.066 |
| Stop remittance | 11.17 | 6.25 | 18.00 | 12.124*** |
| Health shock | | | | |
| Serious illness | 25.98 | 39.42 | 7.33 | 46.670*** |
| Job loss | 9.22 | 7.21 | 12.00 | 2.388 |
| Crime shocks | | | | |
| Fire hazard | 2.79 | 3.85 | 1.33 | 2.027 |
| Theft or banditry | 1.68 | 2.88 | - | 4.400** |
| Crisis migration | 16.76 | 3.37 | 35.33 | 63.841*** |

*Percentage cannot be added to 100 as households can have more than one shocks
***, ** significantly different at $P < 0.01$ and $P<0.05$ respectively

Risk coping strategies distinguished among households over time according to their preferences, objectives, and the capacity to change (Trærup and Mertz, 2011). About 48 percent of rural households were preferred *iddir* risk coping strategies to keep consumption fluctuation during adverse shocks. Informal risk coping arrangement supports the household's effort to maintain food consumption fluctuation against adverse climatic shocks in developing countries (Habibov and Afandi, 2017).

Rural financial institutions are inefficient and have limited outreach in the study area. Nonetheless, but about 21percent of households still borrow from MFI to smooth food consumption during adverse shock events. However, spatially covariate shocks are not easily absorbed by the former two risk coping mechanisms in developing countries, including Ethiopia, indeed requires the intervention of public institutions. Specifically, about 57 percent of households engaged in food for work under the PSNP framework to avoid consumption shortfalls. Finally, 0.56percent of households did not employ any risk coping strategies. Public transfers are an essential risk coping strategy for spatially covariant climatic shocks to protect from depleting liquid assets in developing countries (Wainwright and Newman, 2011).

Table 5.3 Major institutional arrangement risk coping strategies

| Institutional arrangements | Percent | | | $\chi^2 -$ value |
|---|---|---|---|---|
| | All | Hawzen | Irob | |
| Informal institutional arrangements | | | | |
| *Iddir* support | 47.49 | 79.33 | 33.33 | 202*** |
| Market institutional arrangements | | | | |
| Loan from MFI | 21.23 | 35.1 | 2.00 | 57*** |
| Public institutional arrangements | | | | |
| Government support (FFW) | 56.70 | 50.96 | 64.67 | 7** |

***, ** significantly different at $P < 0.01$ and $P<0.05$

In the absence of efficient risk coping institutions, intra-household risk-sharing is effective in sharing risk among its members (Kazianga and Wahhaj, 2017). The consumption-based or non-depleting strategy is a behavioral adjustment coping strategy commonly observed to smooth consumption during idiosyncratic risks. Consistently, food-insecure households in South West Ethiopia employed consumption-based adjustment as coping strategies, such as reducing meal frequency and changing consumption patterns, *inter alia* (Asesefa Kisi *et al.*, 2018). Alike to elsewhere in rural Ethiopia, limited portion size at mealtime, reduce the number of lunches eaten per day, and borrowed food from relatives was the major coping strategies households employed in the study area (Table 5.4). Karrayu farmers' in rural Ethiopia adopt the self-deprivation of food as a risk coping strategy during periods of food shortage by skipping meals (Getachew *et al.*, 2014).

Table 5.4 Intra-household risk-coping strategies per week

| Risk-sharing coping strategies | Percent |
|---|---|
| Limit portion size at mealtime | 26.26 |
| Reduce the number of lunch eaten per day | 19.22 |
| Borrow food or rely on help from relatives | 5.59 |
| Skip adult consumption for the entire day | 3.07 |
| Children skip the entire day without eating | 1.12 |

### 5.4.2.Econometric model results

The likelihood ratio test ($\chi^2(3) = 25.49$, $P < 0.01$) of the null hypothesis that the covariance of the error terms across equations is not correlated is highly rejected as reported in Table 5.5. This implies that the pairwise correlation coefficients of the residuals of the three risk coping strategies are strongly correlated among the error terms. Thus, the alternative hypothesis of the mutual interdependence among the multiple risk coping strategies were adopted. This justified that the MVP model is valid than the other binary regression model.

Two pairwise coefficients reported a positively correlated indicating complementarity among these strategies. Specifically, informal and market based institutional arrangement strategies ($\rho12$) are positively correlated indicating that households adopt both informal and market-based risk coping institutional arrangements simultaneously. Dercon *et al*. (2014); Takahashi *et al. (*2018) found that index insurance and social networks used instantaneously in rural Ethiopia. Whereas, informal and public risk coping institutional arrangements ($\rho23$) is significantly and negatively associated. Then, households who adopted informal institutional arrangements may not require public institutional arrangement risk coping strategies and vice-versa. Moreover, market-based and public institutional arrangements ($\rho13$) are substitutability as expected.

Table 5.5 Covariance of the error terms and likelihood ratio test.

| Correlation pair | Coefficient | Standard error |
|---|---|---|
| Informal and market institutional arrangements ($\rho12$) | 0.1090 | 0.1232 |
| Informal and public institutional arrangements ($\rho23$) | -0.2849** | 0.1156 |
| Market and public institutional arrangements ($\rho13$) | -0.5469*** | 0.0994 |

Likelihood ratio test of $rho21$ = $rho31$ = $rho32$ = 0: $chi2$ (3) = 25.49 $Prob$ > $chi2$ = 0.01

***, ** significance level at P<0.01 and P<0.05 percent respectively

The MVP regression model result reported in Table 5.6 indicated that the hypothesis all regression coefficients in each equation are jointly equal to zero is rejected ($\chi^2$(48) =159.28 with P<0.001). Consequently, the model is relevant for explaining the influence of the independent variables of households to select the different risk coping arrangements.

The likelihood of choosing informal risk coping strategy was significantly higher among males than female-headed households, but males are less likely inclined on public risk coping strategies. Because, male-headed households have better access to the community-based organization and local information than female-headed households (Ragasa *et al*., 2013). In contrast, female-headed households potentially constrained to participate in informal risk coping arrangements due to limited resources and information (Wilson and Getnet, 2011). The results also showed that households with access to credit increased the likelihood of choosing market risk coping but reduce the likelihood of choosing public risk coping arrangements at different significance level. Since access to credit relaxes liquidity constraints then households are more encourages to choose market-based arrangements (Wainaina *et al.*, 2016). As a result, rural households protect themselves against temporary income shocks despite the available financial markets are more imperfect (Alem and Söderbom, 2012). Households' with access to motor road increased the likelihood of choosing a market risk coping strategy but decreased the probability of using a public risk coping strategy. Access to road motor transport facilitates information and communication exchange thereby increase the likelihood of a household's inclination on market-based risk coping strategies during climate change impacts (Gajanayake *et al.,* 2018).

The propensity of rural farmers to choose informal risk coping strategies decreased significantly with farm size because the land is a proxy measure of wealth status (Mehar *et al.,* 2016). Farmers with relatively small farm size adopted less capital intensive and traditional technologies hence impend productivity and food security (Asfaw *et al.,* 2019). Increased distance to the input-output market decreased significantly the likelihood of choosing a market-based risk coping strategy but increase the propensity of relying on public arrangements risk coping strategies. This is in line with the findings of (Maddison, 2007) who suggested that households further away from the market center less likely to rely on the market due to information asymmetry and high transaction costs. As a result, households enforced to opt for public arrangement risk coping strategies to address climate change impact (Kaliba *et al.,* 2000). Access to the input-output market improves the well-being of poor rural households in developing countries (World Bank, 2012).

Livestock holding decreased significantly the probability of a household's decision to opt public risk coping strategy. Because households with large livestock holding earn additional income through destocking during adverse climatic shocks. This result is in line with studies (Tizale, 2007; Gebrekidan *et al.,* 2019) in Ethiopia. Households with irrigation potential decreased the propensity of choosing public risk coping strategy to smooth food consumption. Because, households with irrigation potential increased food security status during climate extreme hardship in Ethiopia (Yigzaw *et al*., 2019). Consistent with this argument, Gbetibouo (2009) underlined that households with irrigation potential are more resilient to climate change impacts hence, less likely to depend on public grant programs.

Households with CBHI increased the likelihood of informal and public arrangement risk coping strategies. In June 2011, the government of Ethiopia introduced a voluntary CBHI in thirteen rural districts of the country. The PSNP increased the probability of CBHI uptake by 24 percent in rural Ethiopia (Shigute *et al*., 2017). Hence, according to these authors, the direct relation between CBHI and public risk coping strategy emanated from the explicit and implicit pressure indorsed by government officials on PSNP beneficiaries to purchase health insurance, though, they are poor and prefer informal risk coping arrangements. Households owned TV/radio increased significantly the propensity of deciding informal risk coping strategy but less likely to choose public risk coping strategy. Access to TV/ radio is helpful to influence risk coping measures that could be used at the local level (Abid *et al. (*2015).

Erratic rainfall worsens farmers' vulnerability to climate change impacts that cause a persistent drought in northern Ethiopia (Falco, 2014). As a result, households from *Alitena* and Hareza Kebele (high negative rainfall trend) are less likely to choose informal and market risk coping strategies but more potentially to choose public arrangement risk coping strategies. This indicates that the probability of choosing a public arrangement risk coping strategy is positively influenced by a negative rainfall trend. Among the common coping strategies during high rainfall variability that depresses the livelihoods of rural households is relief aid (Fjelde and Uexkull, 2012).

Table 5.6 Results of multivariate probit regression model (n=358)

| Dependent variable | Informal arrangements | | Market arrangements | | Public arrangements | |
|---|---|---|---|---|---|---|
| | Coef. | Std.err | Coef. | Std.err | Coef. | Std.err |
| Sex | 0.6566*** | 0.2252 | -0.2200 | 0.2809 | -0.6142** | 0.2858 |
| Age | 0.0085 | 0.0071 | -0.0073 | 0.0098 | 0.0004 | 0.0089 |
| Family size | 0.0432 | 0.0501 | -0.0889 | 0.0694 | -0.0433 | 0.0620 |
| Credit | 0.2005 | 0.1732 | 0.7950*** | 0.2125 | -0.3804* | 0.1958 |
| LnRoad | -0.0176 | 0.0881 | 0.3173*** | 0.1046 | -0.0298 | 0.0962 |
| Farm size | -0.3106** | 0.1586 | -0.0149 | 0.1702 | -0.0892 | 0.1607 |
| Market | -0.0021 | 0.0016 | -0.0062* | 0.0035 | 0.0071** | 0.0031 |
| Livestock | 0.0755 | 0.0528 | 0.0353 | 0.0743 | -0.1318** | 0.0612 |
| Irrigation | 1.0858 | 0.8507 | -0.7250 | 1.0053 | -1.7287** | 0.7884 |
| CBHI | 0.3103* | 0.1709 | -0.2676 | 0.2188 | 0.3911** | 0.1959 |
| TV/Radio | 0.3537** | 0.1638 | 0.1432 | 0.2056 | -0.3266* | 0.1820 |
| Illness | -0.3180 | 0.1969 | 0.0991 | 0.2056 | 0.3472 | 0.2170 |
| Drought | -0.0517 | 0.0318 | -0.0105 | 0.0496 | -0.0199 | 0.0107 |
| Rf_Ali | -0.7655** | 0.3888 | -1.9 155*** | 0.5611 | 0.8754** | 0.4466 |
| Rf_Har | -0.6962 | 0.4523 | -1.1907* | 0.6845 | 1.0788* | 0.6174 |
| Rf_Deg | 0.1197 | 0.2273 | 0.2872 | 0.2219 | 0.1555 | 0.2284 |
| Constant | -0.4259 | 0.4588 | -0.4091 | 0.5954 | 1.4638*** | 0.5577 |

Wald chi-square (48) = 159.28

Prob > chi2 = 0.001

Log likelihood = -431.75

***, **, and * significance level at P<0.01, P<0.05 and P<0.1 respectively

## 5.5. Conclusion and recommendation

Rural households employed various risk coping arrangements to address the multi-faceted climate change consequences. Three main conclusions can be drawn from the results of this study. First, the most commonly reported adverse climatic shocks households exposed to vulnerability were drought (70 percent), livestock death (60 percent), and flood (44 percent), respectively. Rural households use informal and formal risk coping institutional arrangements to smooth food consumption. More specifically, 75 percent of households choose public risk coping while 61 percent and 26 percent of households opted for informal and market-based risk coping institutional arrangements to smooth food consumption during extreme weather events, respectively. Second, the decisions to choose the three risk coping institutional arrangements are unique to household characteristics and the factors that determine their decisions are also different. Specifically, households choose informal risk coping strategies simultaneously opted for market-based risk coping strategy indicated complementarities among the two risk coping strategies. However, informal and public ($\rho 23$) and market-based and public ($\rho 13$) are substitutability risk coping institutional arrangements. This result showed that households chose a particular risk coping strategy is conditional on the decision of the alternative risk coping strategies. Third, the result indicated that the likelihood of employing the three risk coping strategies significantly associated with sex, access to credit, motor roads, farm size, input-output market, livestock, irrigation, CBHI, TV/radio, and annual rainfall trends.

These results have important policy implications that improve households' risk coping strategies in the study area. First, the FDRE national disaster prevention and preparedness strategy should consider the role of rural informal risk coping arrangements during extreme weather events. Second, market-based risk coping arrangements was the least employed strategy in the study area. Hence, policymakers and development planners should take into account promoting MFI outreach and introduce microinsurance products to increase households' risk coping capacity. Third, encouraging women participation in informal risk coping institutional arrangements (*iddir*) to facilitate information exchange and risk-sharing during extreme weather-related shocks. Finally, the empirical findings suggest there is a need for policies that improving household education status that promotes household thinking capacity when determining the optimal trade-off among the observed substitutability risk coping strategies.

# Chapter Six

## 6. Synthesis

### 6.1.Introduction

Theoretical studies and empirical evidence recognize climate change is a real and worldwide threat, especially in developing countries since their livelihood capitals predominantly depend on rain-fed agriculture. Climate change-related impacts have observed at national, regional, and household-scale manifested by warming climate systems, extreme weather events, and sever frequent drought and flood. The intensity and frequency of these impacts have significantly increased over the past century. As a result, the challenges of climate change has been shifted into human developmental agenda than a simple environmental phenomenon by mainstream global and national development plans to achieve an objective a world without hunger.

Ethiopia is highly vulnerable to climate change and variability impacts due to high reliance on rainfall regulated agriculture and adaptation based on natural resources for livelihood sources. The marginal poor rural households have limited capital resources to respond to climate change impacts. However, the Ethiopian National Adaptation Program of Action identifies vulnerability to food insecurity is significant due to frequent extreme weather events and poor adaptation measures. Therefore, adaptation and risk coping measures against climate and none-climate stresses are the main characteristics of rural households that heavily depend on climate-sensitive production systems like, Ethiopia.

This final chapter presents conclusions and recommendations based on the findings obtained under the context of farmer’s perception, livelihood vulnerability, and risk coping strategies under a changing climate. The first section of this chapter summarizes the major findings of the study based on the predetermined research questions presented in Chapter one. The second section of this chapter provides recommendations for policy implications and suggestions for future research.

### 6.2.Summary of the study

Eastern zone, Tigray region is characterized by high exposure to climate change, diverse ecological zones and socio-economic conditions. Therefore, in order to capture the long term spatiotemporal rainfall and temperature trends and livelihood vulnerabilities this study was presented in reference to Hawzen and Irob districts. Understanding these trends and degree of vulnerability is important to develop a risk coping strategy to deter the potential impacts on the farmers. This begins by exploring farm households' perceptions about rainfall and temperature *vis-à-vis* the long term meteorological data (**Chapter 2**). Exploring farmer's perception and climate information is helpful for successful adaptation strategy especially under imperfect market. Smallholder farmers' perception have influenced adaptation strategies to moderate climate change impacts. Hence, farmers need to have perception whether their local climate is changing or not before adaptation takes place (Tripathi and Mishra, 2016). Empirical study revealed that farmer's perception influences adaptation decision in developing countries including Ethiopia (Fadina and Barjolle, 2018). The result indicated high inter-annual rain fall variability, erratic rainfall with severe meteorological droughts and change in temperature. Moreover, the lowest and highest mean annual temperature was rising in both districts progressively. Generally, the result indicated that farmers' perception of decreasing rainfall and an increased temperature was in line with meteorological records **(Hailay *et al*., 2019).** Adaptation is broadly recognized as a crucial element of any policy response to adverse climate change. Some of the adaptation measures were WSC, planting trees, crop varieties, changing crop planting times, biological conservation, and irrigation practices to address climate change impacts. When implementing adaptation process there exist different factors which determine the effectiveness of adaptation with different levels of significance attributed to socio economic and biophysical variables (**Hailay *et al*., 2019).**

The decreased rainfall and increasing temperature exacerbated livelihood vulnerability of the poor households. Therefore, in order to determine the degree of livelihood vulnerability analysis at household level were carry out. The household vulnerability depend on sensitivity to external adverse shocks and ability to adapt with natural stress. Households that are likely vulnerable to climate change fairly adopt various adaptation strategies to build sustainable livelihood. Hence, measuring individual household's vulnerability and categorizing them into various vulnerability profile is very essential (**Chapter 3**). This is helpful to identifying the vulnerable household's and the potential adaptation strategy implemented to moderate climate change impacts. It is obvious the distribution of entitlements to socio-economic and physical resources are unevenly divided then emphasis on household as a unit of analysis essential. Consistent with this argument Hawzen was found relatively less vulnerable than Irob district to climate change impacts (**Chapter 3**). Moreover, the study revealed that rural households with more livelihood assets and entitlements could cope better with climate change impacts than their counterparts (**Chapter 3**).

The SLF examines how households distribute capital assets to generate sustainable livelihoods. This approach has a vital insight how households are exposed and able to own sustainable livelihood from climate-related impacts. Livelihood outcome encompass various components like sustainable food security though it inhibited by extreme stresses attributed to adverse climate change. Food systems can be vulnerable to external environment and endogenous socio economic factors leads to food consumption fluctuation. Food insecurity vulnerability is the primary step towards applying adaptation strategies to reduce climate change impacts to achieve national food security targets. The main aim of this study was to examine vulnerability to food insecurity due to extreme climatic events using the vulnerability as expected poverty technique **(Chapter 4).** Because, in Ethiopia majority of the empirical studies focused exclusively on current food security but dynamic food security analysis remained scanty yet. Congruently, several empirical findings revealed that food security in developing countries is unstable hence a food secure household at any point may be move in to food insecure in time caused by extremes stresses. Consistent with this proposition the present study revealed that the number of households vulnerable to food insecurity was higher than those who are currently food insecure **(Chapter 4).**

Successful risk coping strategy can reduce the propensity of households fall in to vulnerability. Poor households in developing countries like Ethiopia face several uncertainties ranges from extreme weather events, market imperfection, and supply constraints make households vulnerable to various climatic and non-climatic shocks. To overcome these adverse shocks households' employed risk management (ex-ante) and risk-coping (ex-post) strategies stemming from informal risk sharing to public support. This study provides attention to analyses the potential determinants of risk coping strategies using the rural institutional arrangements caused by extreme climate change **(Chapter 5).** There are various climate-related risks like droughts, livestock death and floods that affect the livelihoods and farming systems of the smallholder farmers. However, rural institutions are crucial to smooth consumption fluctuation to mitigate adverse climate change. Broadly, this institutions categorized in to informal and formal arrangements then households substitute or complement these risk coping mechanisms based on the nature of the shocks under consideration.

## 6.3.Conclusions

This study has developed integrated analytical frameworks to address the four interdependence objectives. Then first investigates the link between smallholder farmers' perceptions and long term climate data trends and influence on adaptation decisions to climate change extreme weather events. Second, measure individual households' livelihood vulnerability to change and variability. Third, decomposing, and analyze the factors that influence household vulnerability to food insecurity. Fourth, identify the major idiosyncratic and spatial covariant shocks households encountered and the factors affecting to choose the various risks coping institutional arrangements to smooth food consumption in semi-arid eastern highlands of Tigray, northern Ethiopia.

Chapter two investigates farmers' perceptions and adaptation to changing climate. Smallholder poor farmers' have been reacting to various risks differently according to their ability to analyze information and perception capability about the expected hazards. According to the findings result, the majority of the farmers perceived the climate is changing in the study area. More specifically, about 99 and 92 percent of farmers' perceived annual rainfall was decreased in Hawzen and Irob Districts, respectively over the last fifteen years. Correspondingly, the analysis of long-term meteorological data confirmed that the annual rainfall trend was decreased for the period of analysis. Moreover, nearly 87 and 90 percent of farmers' perceived an increased temperature which was also verified by the meteorological data. The congruence between farmers' perceptions of climate change and meteorological data has a significant policy implication particularly under limited weather information dissemination systems if farmers rely on indigenous knowledge and farm experiences.

The long term mean annual rainfall disproportionately varies from 614 mm to 471mm and the high variability ranges from 48 percent to 59 percent in Hawzen and Irob, respectively throughout the analysis. Negative annual rainfall anomalies range from 63 percent in Irob to 79 percent in Hawzen of the total observations implies high frequency and severity of meteorological droughts in the study area. The long term annual temperature analysis revealed a warming trend with trivial deviations in both districts. Irob reported slightly higher mean temperatures (19.92$^0$C) than Hawzen (19.18$^0$C). Besides, the lowest and the highest mean temperature was 25.61$^0$C and 28.38$^0$C reported in 1986 and 2013 while 26.86$^0$C and 30.00$^0$C in 1989 and 2008 in Hawzen and Irob respectively imply temperature was rising gradually during the period of analysis. Farm households use various coping strategies to reduce the decrease in rainfall and increasing temperature. SWC (87.71percent), planting trees (84.64 percent), and crop varieties (81percent) were among the wide adaptation strategies to moderate climate change impacts, respectively.

The results of the Heckman probit models indicated that age of household head, household size, access AES, the number of off-farm activities, and access to weather information increased significantly WSC adaptation decisions but a decrease in annual rainfall increased significantly WSC adaptation strategy.

Chapter three measured individual household's vulnerability to climate change and variability. Smallholder households are most vulnerable since their livelihood capital assets depend on the climate-sensitive agricultural sector. In Ethiopia, ample empirical studies assess the impact of climate change and variability at the national and regional levels but less attention has been paid to measure vulnerability at the household level. Therefore, measuring individual household livelihood vulnerability to climate change-related extreme weather events is the aim of this chapter. To construct a complete livelihood index and measure the degree of household livelihood vulnerability, the integrated vulnerability assessment method, and the sustainable livelihood framework approach were applied.

The HVI was calculated from the three components of vulnerability as the net effect of sensitivity and exposure on the adaptive capacity after weights are assigned using the multivariate statistics PCA method. Accordingly, the HVI indicated that farming households dwelling in Hawzen were significantly less vulnerable in terms of adaptive capacity (1.358) to climate change and variability than those in Irob district (0.791). Furthermore, households in Hawzen showed lower exposure index value (0.109) compared to Irob (0.605) while both groups reported an equal sensitivity index. Therefore, the overall net HVI for Hawzen (0.875) was higher than those in the Irob district (-0.188) indicates that Hawzen had a relatively lower vulnerability than Irob to climate change and variability. Lastly, the K-Means cluster analysis exhibited that 26 percent of households fell within the highly vulnerable while 47 and 27 percent were moderate and less vulnerable to climate variability, respectively. Households with limited or low education, family size, dependency ratio, social networks, food self-sufficiency, farmland size, fertile pot, credit access, and TLU ownership, *inter alia* have higher livelihood vulnerability than their counterparts for climate change and variability.

Chapter four, poor households in developing countries including Ethiopia have unstable and fragile food consumption caused by climate-related extreme weather events and limited adaptive capacity. Therefore, *ex-post* food security analysis overlooked those households more likely to become food insecure soon. But, less attention has been given to *ex-ante* food security analysis indeed *ex-post* food security analysis have been received special focus in Ethiopia. Vulnerability to food insecurity (*ex-ante)* measures the likelihood of food secure households becoming food insecure in the future considering the current characteristics.

Therefore the main objective of this study is to decompose and analyze households' vulnerability to food insecurity to climate and non-climate related extreme shocks. The vulnerability as expected poverty framework estimated the expected and variance food consumption expenditure assuming the current food consumption expenditure and household characteristics. Moreover, the food poverty line was defined as equivalent to the minimum food energy intake i.e., 2,200-kilocalories per day per AD required for a healthy life then converted into monetary value.

The FGT revealed about 82 percent and 87 percent of households in Hawzen and Irob were currently food insecure hence at least 42 percent and 58 percent in mean food consumption expenditure required to achieve food security, respectively. The vulnerability to food insecurity analysis showed that about 84 percent and 93 percent of households of the total households categorized as current and future food insecurity implies that the number of future food insecure households higher than the current food-insecure households in the study area. The three-step FGLS result shows that future food consumption expenditure was increased with dependency ratio, livestock size, irrigation potential, livestock death, energy cost, and positive rainfall trend in *Degamba Kebele* whereas decreased with family size and negative rainfall trend in *Alitena Kebele*.

Chapter five examines the factors that determine the household's decision to choose the three institutional arrangements to reduce the perceived decreasing rainfall. Rural households in Ethiopia employed various risk coping mechanisms like liquidating livestock assets, farm-level adjustments, and diversifying their livelihood sources to smooth consumption fluctuation. However, limited attention has been provided to the joint function of rural local institutional arrangements as risk coping mechanisms to keep food consumption fluctuation. The three worst climatic shocks households experienced over the previous ten years are drought 70 percent, livestock death 60 percent, and flood 44 percent, respectively statistically significant at (P<0.01). Risk coping strategies vary between households according to preferences, objectives, and the capacity to change. Specifically, 75 percent of households employed public institutional arrangements while 61 percent and 26 percent of households opted for informal and market-based arrangements to smooth food consumption during adverse events, respectively. Moreover, households engaged in a consumption-based risk coping strategy to smooth consumption during idiosyncratic shocks. Households could be complemented and/or substituted rural institutional arrangements risk coping mechanisms according to the nature of the shocks they encountered. The MVP result revealed that the likelihood of deciding informal, market-based, and public arrangement risk coping strategies significantly increase among male-headed, access to credit, road, distance to market, CBHI, TV/radio ownership, and annual rainfall in Irob district.

## 6.3 Recommendations

The results of this empirical study help to provide policy recommendations to reduce livelihood vulnerability and increase response measures to climate change-related extreme weather events implemented by various stakeholders. The policy implications and the lessons that are drawn from the empirical results of this study are briefly summarized as follows undertaken in the study area.

1. *Create an enabling environment that facilitates weather information exchange*

   Successful adaptation decisions followed three interrelated processes. First well perception about the hazards encountered then decide whether to adopt or not among the various adaptation measures and lastly implement the selected adaptation measures. Therefore, access to updated weather forecasting information coupled with their perceived ability to climate-related weather events is necessary. These could be achieved through the following measures: first, local government should mainstreaming and disseminating meteorological weather information into agricultural extension services to increase farmers understanding of climate change and variability. Second, when weather information remained imperfect households are relied on local social networks as alternative sources of information to facilitate adaptation measures. Hence, promoting rural social networks and family ties are essential to exchange weather information and successful early warning systems. Third, promoting the factors that increased adaptation measures to reduce negative climate change impacts.

2. *Promoting long term and short term public investment on livelihood capital*

Those households with low education enrollment, social networks, food availability, fertile plot, and credit were more vulnerable than their counterparts. Hence, local government and NGOs should increase long term investment in human capital development and sustainable land management schemes. Moreover, encourage the outreach rate of rural financial institutions that provide micro-credit loans to relax households' liquidity constraints during hardships. Carful public investment on physical capital in Irob district is critical to reducing the time took to reach the basic public goods. The overall HVI shows that one out of four households were highly vulnerable to climate change and variability. Thus, emergency food assistance programs such as PNSP is required to maintain their livelihood capital.

3. *Ensuring sustainable food security programs to reduce food consumption fluctuation*

   The number of vulnerable households was exceeded than those who are currently food insecure in the study area. Therefore introducing sustainable food security policies that focus not only on the current food insecure households but also on those who are more probably being food insecure soon. Therefore, food security programs should give due attention to development projects that have positive impacts on household's long term food security than exclusively reducing short term food insecurity crisis. In this regard, fostering a family planning program and irrigation scheme is among the critical policy interventions to enhance sustainable food security thereby reduce frequent food consumption instability.

4. *Optimizing the functions of rural institutional arrangements as risk coping strategies*

   Poor rural households depend on informal rural institutional arrangements, such as *Iddir* and family networks to smooth food consumption fluctuation when the market is imperfect. Therefore, the FDRE national disaster prevention and preparedness strategy should consider these arrangements for risk-sharing purposes through planned support and follow up. Promoting inclusive financial services that provide microcredit and index insurance includes rainfall and crop insurances are helpful to build sustainable livelihood outcomes.

## 6.4. Contributions of the study

**Conceptually:** smallholder farmer's perception, decision, and adaptation mechanisms are among the basic research topics in sustainable development studies. Particularly, perception is subjective and wide-open for misconception though it is a prerequisite for a successful adaptation process. Moreover, the adaptation process is conceptualized interdependently to avoid misconceptions and determine the influence of perception on adaptation measures. The study has contributed towards conceptualizing vulnerability to food insecurity which has been remained open to misunderstanding. The study conceptualizes how the various rural institutional arrangement used as risk-pooling and sharing mechanisms to withstand climate change and variability.

**Theoretically:** anthropogenic global warming theory of climate change together with non-climatic factors, has been paid attention to the analysis of the impacts of climate change on livelihood capitals and outcomes. A substantial effort made to measure household vulnerability to climate change and variability consistent with the integrated vulnerability assessment approach which involves adaptive capacity, sensitivity, and exposure components. Moreover, this study applied vulnerability to food insecurity approach as households welfare measurements derived from theories of poverty. Therefore, this study empirically tested how these theories are applicable in the context of semi-arid highlands of Eastern Tigray, northern Ethiopia. Furthermore, most of the chapters studied are closely associated with Sustainable Development Goals, which would be significant to evaluate the effectiveness of the present development interventions.

**Methodologically:** a long-term 4 km by 4 km gridded data utilized to measure annual rainfall and temperature trends at District and *Kebele* level to capture the main characteristics of climate change in the study area. The majority of the previous studies analyze perception and adaptation independently. However, this study understood perception and adaptation decisions as a two-step process hence examined using econometric techniques to capture the full adaptive process. The other methodological contribution of this study is measuring individual household's vulnerability using PCA and K-means cluster analysis methods which were scarce in Ethiopia. Unlike, most of the previous studies that focus on current food insecurity analysis this study gives special attention to vulnerability to food insecurity using poverty as expected vulnerability and FGT methodology. Such results will help to develop context-specific policies aimed at building resilience livelihood and reducing food security instability.

**Empirically:** using gridded data set to measure long term rainfall and temperature trends at *kebele* level then associate with local farmers' perception has a vital empirical contribution under limited weather information dissemination particularly in the study area. Moreover, **t**his study provides an empirical contribution since it classified households into unique vulnerability categories according to their degree of vulnerability.

## 6.5. Suggestion for future research

The following recommendations are forward for future research.

- Measuring vulnerability at the individual household level is very difficult since there is no long term panel data at the household level the model depends. Hence, the majority of prior empirical studies alternatively depend on a cross-sectional data survey to measure a household's vulnerability but it disregarding the inter-temporal variability over time. To overcome the limitations of cross-sectional data subsequent research is suggested to apply panel data together with covariant shocks to capture the stochastic nature of food consumption over time.
- Climatic and non-climatic shocks experienced over the last ten years were analyzed based on households' self-reported data. However, self-reported data can contain several potential sources that may potentially bias the result of the study. To address such drawbacks of self-reported data further research required to include secondary data extracted from remote sensing satellite data, particularly the climatic extreme events.
- Despite household is the unit of analysis in this study, meteorological long term annual rainfall, and temperature data at *Kebele* level was used as a proxy for household's spatially covariant shocks. Hence, upcoming studies advice generating household level climate data using GPS reading at the plot level.
- This study mainly focuses on access and stability dimensions of food security. Hence, additional research is recommended to analyze the impact of climate change and variability on crop productivity and agriculture using a Ricardian approach.

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# Appendices

## Annex 1.1. Household survey questionnaire

Addis Ababa University
አዲስ፡አበባ፡ዩኒቨርሲቲ
SEEK WISDOM, ELEVATE YOUR INTELLECT AND SERVE HUMANITY !

***Household Survey questionnaire***

**Household profile**

*Woreda Name*: ____________________

Peasant association /*Kebele*: __________

Name HH head: _________________

Household ID: _______________

Interviewer's Name: ____________

Date of Interview: ___________________

Signature of Interviewer ______________

Checked by (Supervisor): ______________

Date Checked: _____________________

Signature of (Supervisor): ______________

Comments by Supervisor:

__________________________________________________________________________________

_________________________________________________________________

### *Information and Instruction*

1) The research is done by ***HailayTsigab*** (a PhD Candidate in Addis Ababa University, Ethiopia)

Cell phone: +251 914019280.
E-mail: hailay20@gmail.com

2) Title: "Households' Vulnerability, Food insecurity and Risk Coping Strategies under the Changing Climate: in the semi-arid highlands of Eastern Tigray, Northern Ethiopia"

2) The data will be used for *academic purpose* ONLY (doing Ph.D. dissertation) and possibly for development intervention;

3) Hence, the importance of your *genuine* response is essential for the reliability of the result.

*4)* **Mark(X)** for each answers corresponding to each box.

*Thank you*

# 1. Social Capital

**1.1.**Demographic characteristics of HH head (*who eats and sleep in the house)*

| S/No | family members including the head | Sex *Male=1* *Female=0* | age (years) | Highest grade completed? ( years) 0= *Did not complete any schooling* | Marital Status *Single=0, Married =1, Divorced =2, Widow =3* |
|---|---|---|---|---|---|

| | | | | | |
|---|---|---|---|---|---|
| 1 | | | | | |
| 2 | | | | | |
| 3 | | | | | |
| 4 | | | | | |
| 5 | | | | | |
| 6 | | | | | |
| 7 | | | | | |
| 8 | | | | | |
| 9 | | | | | |
| 10 | | | | | |

### *1.2.Groups, Networks, and Collective Action*

**1.2.1.** Did your family receive help over the past one year (free food, goods in kind, worked in field, agricultural input) from the government or a non-governmental institution?
**Yes= 1** ☐ **No=0** ☐

**1.2.2.** Did you and/or your family *give* help for others in the past one year (medical care, goods in kind, food, and worked in field)? **Yes=1** ☐ **No=0** ☐

**1.2.3.** Are your families in land-renting arrangement last year? **Yes =0, No=0**

**1.2.4.** Do you belong to any social networks (like Iddir and Equb) over the last one year?
**Yes=1** ☐ **No=0** ☐

**1.2.5.** In how many community based organization (CBO) did you have membership? _____

**1.2.6.** Did your family membership of *Iddir* ***Yes*** ☐ ***No*** ☐

**1.2.7.** If you say ***yes*** what is the role of iddir in mitigating shocks in your family in 2009/10?

| S/No | Adverse events | *Iddir* gave a cash transfer **Yes=1, No=0** | *Iddir* gave a loan **Yes=1, No=0** |
|---|---|---|---|
| 1 | Wedding | | |
| 2 | Loss of oxen or other livestock | | |
| 3 | Fire hazard | | |
| 4 | Destruction of house | | |
| 5 | Illness | | |
| 6 | Harvest loss | | |
| 7 | Funeral service | | |
| 8 | Other events, specify ___ | | |

## 2. NATURAL CAPITAL

### *2.1.Land resources*

| S/No | Land type | size in **Tsimad** | Share of fertile land to cultivated land |
|---|---|---|---|
| 1 | Own Cultivated farm size | | |
| 2 | Irrigable land | | |
| 3 | Rage land | | |

| | | | |
|---|---|---|---|
| 4 | Others, specify | | |
| | Total | | |

**2.1.1.** How is the productivity of your cultivated land per hectare since you started farming? Increased=1,Decreased=2, No change=3, I don't know =4

**2.1.2.** If your answer is **decreased**, what are the reasons for the decline of productivity of your cultivated land?
Land degradation =1, Drought =2Pests and crop diseases =3, other specify, ____

**2.1.3.** Did your farm land affected by flood the last ten years? Yes 1, No 0

**2.1.4.** If **Yes** how many farm lands affected by flood? **Tsimad _________**

### 2.2.Crop production

**2.2.1.** How many quintals of cereals did you produce in 2008/9 ______________

***2.2.2.*** Crops type and land cultivated in 2008/2009?

| *S/No* | crop type | Cultivated land (*tsimad*) | Harvest (in Quintals) | Sales revenue (Birr) |
|---|---|---|---|---|
| *1* | *Cereals* | | | |
| *1.1* | Teff | | | |
| *1.2* | Wheat | | | |
| 1.3 | Barley | | A. | |
| *1.4* | Maize | | | |
| *1.5* | Sorghum | | | |
| *1.6* | Millet | | | |
| | Others, specify | | | |
| *2* | *Vegetables and fruits* | | | |
| *2.1* | Tomato | | | |
| *2.2* | Potato | | | |
| *2.3* | Onion | | | |
| *2.4* | Carrot | | | |
| *2.5.* | Fruits | | | |
| *2.6* | Pepper | | | |
| *3* | **Pulses** | | | |
| *3.1* | Beans | | | |
| *3.2* | Peas | | | |
| *3.3* | Lentils/msir | | | |
| *3.4* | Gaya | | | |
| *3.5* | Chick peas | | | |
| *3.6* | Oilseeds | | | |
| *3.7* | Other, specify | | | |
| | Total | | | |

**2.2.3.** Does your family save seeds to grow the next year? **Yes=1, No=0**

**2.2.4.** If yes how many quintals? ________

### *2.3 Agricultural inputs, practices and expenditures in 2009/10*

| No | Agricultural input and technologies | Unit | If yes amount used unless "0" | Total payment (Birr) |
|---|---|---|---|---|
| 1 | Fertilize (Urea or Dap) | Quintal | | |

| | | | | |
|---|---|---|---|---|
| 2 | Improved seeds | Kg | | |
| 3 | Pesticides | Lit | | |
| 4 | Insecticides | Lit | | |
| 5 | Water and soil conservation of the total land | Hector | | ▨ |
| 6 | Labor for crop production | Birr | | |
| 7 | Transport | Birr | | |
| 8 | Rent for oxen | Birr | | |
| 9 | Other, specify | | | |
| 10 | Total | | | |

### *2.4.Energy Sources*

**2.4.1.** What is/are the energy sources for cooking food, heating and lightening in your house over the last one year?

| S/No | Energy source | **Did you use?** Yes=1, No=0 | monthly expenditure (Birr) |
|---|---|---|---|
| 1 | Collected Fuel wood | | ▨ |
| 2 | Purchased fuel wood | | |
| 3 | Wastes of crop, Dung | | ▨ |
| 4 | Gas (kerosene) | | |
| 5 | Biogas | | |
| 6 | Solar energy | | |
| 7 | Improved stove | | |
| 8 | Electric power | | |
| 9 | Other, specify | | |
| 10 | Total | | |

**2.4.2.** What is the situation of availability of fire wood in comparison to 10 years back?

Increased =1, decreased =2, Same as before=3, I don't know=4

### *2.5.Climate variability/change*

**2.5.1.** Have you observed rainfall variability in the past 15 years in your locality?

Yes =1, No=2, stayed the same=3, no opinion=4

**2.5.2.** If **yes**, what are the local *perceptions* of rainfall variability in your community?

Variability in starting (onset) and ending (cessation) time of *rainy season=1*
Number of rainy days decreased=2
The intensity of rainfall increased =3
The occurrence of untimely rainfall increased =4
Drought occurrence frequently increase=5

**2.5.3.** Have you observed *temperature* variability in the past 15 years in your locality?

Yes = 1, No=2, stayed the same=3, no opinion=4

**2.5.4.** If **yes**, what are the local perceptions of *temperature* variability in your community?

Temperature increases =1
Number of hot days increased =2
Number of warm nights increased =3
The coldness of cold seasons decreased=

**2.5.5.** What primary adaptation strategy did you use to counteract climate change?

| S/No. | adaptation strategy | **Yes=1, No=0** |
|---|---|---|

| | | |
|---|---|---|
| 1 | Soil and water conservation | |
| 2 | Crop varieties | |
| 3 | Planting trees | |
| 4 | Changing planting date | |
| 5 | Irrigation | |
| 6 | Biological conservation | |
| 7 | No-adaptation | |
| 8 | Others, specify | |

**2.5.6.** If **no** what are the barriers for not- adapt to climate change?
Lack of information=1, Lack of money=2, Shortage of labor=3, Shortage of land=4, Poor potential for irrigation=5, other, specify ___________________________

**2.5.7.** What is your perception of the impact of climate changes on food availability and *on* economic activities?

| S/No. | *A. Impact of climate change on food availability* | **Yes=1, No=0** |
|---|---|---|
| 1 | production decrease | |
| 2 | Income decrease | |
| 3 | Food price increased | |
| | *B. Impact of climate change on economic activities* | |
| 1 | Decrease working hours on economic activities | |
| 2 | Increased family member migration= | |
| 3 | Decrease livestock rearing | |

### *2.6.Natural Disasters*

***2.6.1.*** Has your household been affected by a serious shock that led to a serious reduction in income and reduction in consumption last ten years?

| No | Shocks | Over the last ten year has any these shocks encountered? **Yes =1, N0=0** | If *yes*, rank the **three** most shocks you experienced?<br>Most Severe (1),<br>Second most Severe (2),<br>Third most Severe (3) | Over the last ten year, how many times did the shock occur? |
|---|---|---|---|---|
| A | **Climatic shock** | | | |
| 1 | Drought | | | |
| 2 | Flood | | | |
| 3 | Death of livestock | | | |
| 4 | Land slides | | | |
| B | **Economic** | | | |

| | | | | |
|---|---|---|---|---|
| 5 | Increase agri input price | | | |
| 6 | Property damage | | | |
| 7 | Remittance stopped | | | |
| C | **Health** | | | |
| 8 | Death of HH member | | | |
| 9 | Illness of household member | | | |
| 10 | Job/business loss | | | |
| **D** | **Criminal** | | | |
| 11 | Fire hazard | | | |
| 12 | Violent/crime | | | |
| 13 | Crisis migration | | | |

**2.6.2.** Did any of your family member died due to climate change over the last ten years
Yes = 1 No =0

**2.6.3.** If **yes** how many individuals died _______________

**2.6.4.** As a result of the three most shocks what are their impact on

| Alternatives | Income | Asset | Food production | Food stock | Food purchase |
|---|---|---|---|---|---|
| Increased=1,<br>decreased=2,<br>did not change =3 | | | | | |

**2.6.5.** How often does conflict arise over natural resource use over the past year in your community (water, grazing, forest, etc )?

Most often=1, Sometimes=2, Never=3

### 2.7.*Events during the last Kiremt season*

***2.7.1.*** Did any of the following events happened to you which affected the growth of your crops and the harvest during the last main rainy season (Kiremt)

| S/No | Events | Code |
|---|---|---|
| 1 | Are the *kiremt* rains important for your crops? | Yes =1<br>No =0 |

| | | |
|---|---|---|
| 2 | According to your own plans, did the first *kiremt* rains come on time? | On time=1,<br>too early =2,<br>too late =3 |
| 3 | Was there enough rain on your fields at the beginning of the rainy season? | Enough= 1,<br>too little =2,<br>too much=3<br>average =4 |
| 4 | Was there enough rain on your fields during the growing season? | Enough=1,<br>too little =2,<br>too much=3<br>average =4 |
| 5 | Did the rains stop on time on your fields? | On time =1,<br>stopped too late =2, stopped too early=3 |
| 6 | Did it rain near the harvest time? | Yes= 1, No=0 |

## *3. HUMAN CAPITAL*

### *3.1.Health*

3.1.1. In which months of the year is malaria particularly outbreak? Mark (X)

| Months | Sep | Oct | Nov | Dec | Jun | Feb | Mar | Apr | May | Jun | Jul | Aug |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| malaria outbreak | | | | | | | | | | | | |

3.1.2. How many mosquito nets did you have in 2008/2009? _____________

3.1.3. Do you have toilet? **Yes=1, No=0**

3.1.4. Have you/ your family member had to miss work or school due to illness over the past one year**? Yes=1, No=0**

3.1.5. How many days has this person been unable to perform his/her main activity at all? ____

3.1.6. Did your family have health insurance over the last one year? **Yes=1, No=0**

3.1.7. Are you willing to pay Birr 240 per year to have health insurance for your household? **Yes=1, No=0**

3.1.8. What will be the initial fee you are willing to pay per year for health insurance? ______

3.1.9. What will be the maximum fee you are willing to pay per year for health insurance? ____

### ***3.2.Food availability and nutrition***

3.2.1. In the last one year, did you have enough food to feed the household? **Yes=1, No=0**

3.2.2. How many months in the last one year did your family has got sufficient food from your own production? Months _________

3.2.3. In which months of the last one year did you experience food shortage? Mark X

| Food shortage Month/s | Sep | Oct | Nov | Dec | Jun | Feb | Mar | Apr | May | Jun | Jul | Aug |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | |

3.2.4. Did you obtained food aid last year? Yes =1, No =0

3.2.5. In the past *7 days*, did you worry that your household would not have enough food due to absence of enough money to purchase?

### ***3.2.6. Training attending and skills***

| Types of training attending | Yes =1 , No=0 | For how many days |
|---|---|---|
| HH member vocational training | | |
| Agricultural extension services in FTC | | |
| Health extension training | | |

| S/No | Impact on family member | how many days have you or someone in your household had to: *(if no days, record zero)* |
|---|---|---|
| 1 | Go a whole day and night without eating | |
| 2 | Cut/limit the size of food at meal time | |
| 3 | Reduce number of meals eaten in a day? | |
| 4 | Adults not eat for a whole day | |
| 5 | Children not eat for a whole day | |
| 6 | Borrow food from a friend/relatives | |
| 7 | Have no food of any kind in your HH | |

### *3.3.Livelihood strategies*

3.3.1. Off-farm income and business activities

| S/No | Non-farm business | Participation yes=1, No=0 | If yes net income (Birr) |
|---|---|---|---|
| | A. *Natural resource based income* | | |
| 1 | Crop trading | | |
| 2 | livestock trading | | |
| 3 | Sales livestock product(milk, butter) | | |
| 4 | Handcraft | | |
| 5 | Sales of firewood/charcoal | | |
| 6 | Sales of eucalyptus tree | | |
| 7 | Sale of Honey | | |
| 8 | Others(specify)______________ | | |
| | *B. Non-natural based remunerative income* | | |
| 1 | Wage labor | | |
| 2 | Sales of local drinking | | |
| 3 | Petty trade/shop | | |
| 4 | Food for work | | |
| 5 | Weaving/spinning | | |
| 6 | Milling | | |
| 7 | Transport (by pack animal) | | |
| 8 | Remittance and gifts/transfers | | |
| 9 | Pension and investment income | | |
| 10 | Rental income | | |
| 11 | Dividends | | |
| 12 | Salary | | |
| 13 | Others income specify)______________ | | |

## 4. Financial capital

### *4.1.Rural financial institutions*

4.1.1. Have you taken out a loan of at least 20 birr, in cash or in kind? **Yes=1, No=0**

4.1.2. If yes from which source did you get your loan?

| S/No | Source of loan | Yes=1 No=0 | Birr | Did u payback on due date Yes=1 No=0 |
|---|---|---|---|---|
| 1 | Money lender | | | |

| | | | | |
|---|---|---|---|---|
| 2 | Relatives | | | |
| 3 | Friends | | | |
| 4 | Equb | | | |
| 5 | Eddir | | | |
| 6 | MFI | | | |
| 7 | Rural saving and credit | | | |
| 8 | Cooperatives | | | |
| 9 | Food security | | | |
| 10 | Other, specify | | | |

4.1.3. Why did you want to obtain a loan?

To buy farm or other tools/implements =1, to buy inputs seeds/fertilizer/pesticides=2, to buy food/goods for the household=3, to buy livestock=4, to start an off-farm business =5

4.1.4. Did you *lend* any money to relatives or friends over the past one year? **Yes=1, No=0**

4.1.5. Specify the amount of Birr _____________

4.1.6. Did you *borrow* any money to relatives or friends? **Yes=1, No=0**

4.1.7. Specify the amount of Birr _____________

4.1.8. Did you save in banks or MFI? Yes=1, No=0

4.1.9. If **yes** what is the total household savings? Birr _______________

4.1.10. Does any member of the household have a bank account? yes=1, No=0

*4.2. Livestock*

4.2.1. Type of livestock owned, number, and income?

| S/No | Type of animal | number | Sales revenue | Livestock death due to climate change |
|---|---|---|---|---|
| 1 | Oxen | | | |
| 2 | Cow | | | |
| 3 | Calves | | | |
| 4 | Heifer | | | |
| 5 | Sheep | | | |
| 6 | Goat | | | |
| 7 | Horse | | | |
| 8 | Mule | | | |
| 9 | Donkey | | | |
| 10 | Camel | | | |
| 11 | Poultry | | | |
| 12 | Bee colony | | | |
| 13 | Other, specify | | | |

## 5. Physical capital

5.1.Did Household currently own any tools in your house?

| S/No | Item name | How many of this item does your household own? If **none** record =0 | Current price (Birr) |
|---|---|---|---|
| 1 | Cylinder gas stove | | |
| 2 | Mattress and/or Bed | | |
| 3 | Mobile Telephone | | |
| 4 | Radio/ tape recorder | | |
| 5 | Television | | |
| 6 | Sofa set | | |
| 7 | Cart (animal drawn) | | |
| 8 | Energy saving stove | | |
| 9 | Shelf for storing goods | | |
| 10 | Biogas pit | | |
| 11 | Sickle | | |
| 12 | Axe | | |
| 13 | Plough | | |
| 14 | Hoe | | |
| 15 | Hammer | | |
| 16 | Table | | |
| 17 | Chair | | |
| 18 | Traditional honey bee colony | | |
| 19 | Modern honey bee colony | | |

5.2.Infrastructure access and institutions

| **S/No** | Infrastructure | Infrastructure access within 1-4Km Yes=1, No=0 | Walking distance from home (minutes) |
|---|---|---|---|
| 1 | All-weather roads | | |
| 2 | primary school | | |
| 3 | health services | | |
| 4 | Veterinary services | | |
| 5 | water source | | |
| 6 | Market (input and output) | | |
| 7 | MFI | | |
| 8 | Credit and saving institution | | |
| 9 | Other, specify | | |

5.3.Access to Information:

5.3.1. Did you obtained agricultural extension services by development agent?

5.3.2. If *yes* how many times during the last cropping season? _____________

5.3.3. Does it helps you to improve your climate change knowledge? **Yes=1, No=0**

5.3.4. Did you receive a warning about the flood/drought /heat/land slide *before* it happened? **Yes=1, No=0**

5.3.5. What is your source for climate related information?
Radio=1, Television=2, Newspaper and magazine=3 , Agriculture experts=4, Neighbors=5, other, please specify________.

## 6. Coping Strategies

6.1.1. Which one of the following coping mechanisms have you adopted to smooth food consumption fluctuation?

| **S/No** | Sub-components of the strategy | Mark (X) |
|---|---|---|
| (A)<br>Informal arrangements | Support from *Iddir* | |
| | Sold livestock | |
| | Causal employment | |
| | borrowed from relatives or neighbors | |
| (B)<br>Formal arrangements | Loan from MFI | |
| | Dissaving | |
| | farmland renting | |
| (C)<br>Public arrangements | Participated in food for work (FFW) | |
| | Received unconditional food aid from government | |
| | | |
| | *Did nothing* | |

## *7. Non-food expenditure*

### *7.1.Last month expenditures*

| S/ No | Item | did your household purchase or pay any item Yes=1, No=0 | How much did you pay ( **Birr**) |
|---|---|---|---|
| 1 | Health insurance | | |
| 2 | Other educational expenses | | |
| 3 | Matches | | |
| 4 | Batteries | | |
| 5 | Candles | | |
| 6 | Hand soap/OMO | | |
| 7 | Body soap | | |
| 8 | Charcoal | | |
| 9 | Firewood | | |
| 10 | Kerosene | | |
| 11 | House rent | | |
| 12 | Transport | | |

## 7.2. *Food consumption*

| S/No | Staple food type | How much did you consume of the following food type over the last week? | |
|---|---|---|---|
| 1 | **A. Cereals** | Unit | Quantity |
| 1.1 | Barley/ Sorghum | KG | |
| 1.2 | Millet | KG | |
| 1.3 | Teff | KG | |
| 1.4 | Wheat | KG | |
| | Other | KG | |
| 2 | **Pulses and Legumes** | | |
| 2.1 | Pea flour | KG | |
| 2.2 | Chick pea | KG | |
| 2.3 | Lentil | KG | |
| 2.4 | *Engaya* | KG | |
| 3 | **Vegetables** | | |
| 3.1 | Onion | KG | |
| 3.2 | Tomato | KG | |
| 3.3 | Potato | KG | |
| 3.4 | Cabbage | KG | |
| 4 | **Fruits** | | |
| 4.1 | Guava | KG | |
| 4.2 | Citron | KG | |
| 5 | Meat | KG | |
| 5.1 | Beef | KG | |
| 6 | **Diary and milk** | | |
| 6.1 | Butter milk (cow) | Liter | |
| 6.2 | Egg | Count | |
| 7 | **Stimulants** | | |
| 7.1 | Coffee beans | KG | |

**Annex 1.2**. Focus Group Discussion (FGD)

### Part I: Introduction/ welcome:

1. Participants introduce themselves after explain the purpose of the group discussion
2. Encourage and respect different opinion, ideas, and thoughts
3. Motivate inclusive participation
4. Explain their suggestion is completely confidential
5. Date of interview: ___________________________
6. Time (duration of interview) from ____________to ____________
7. Name and signature of rapporteur__________________________

### Part II: FGD guideline

1. How do describe the trend of long-term changes in rainfall and temperature in your locality?
2. What changes you observed over the last two decades in relation to rainfall and temperature?
3. What are the frequently occurred adverse shocks in your locality that affects livelihood?
4. Did you get early warning climate change information and its likely impact on livelihood?
5. What are the staple foods commonly consumed in your village?
6. How do you observed the government role to effectively address climatic risk problems?
7. What are the common risk coping arrangements you adopted to overcome climatic stress?

8. How do you evaluate the effectiveness of these risk coping strategies you may apply?
9. What are the major adaptation strategies to address climate change risk impacts?

**Annex** 1.3 Key Informant Interview Guide (for agricultural development agents)

**Part I: Introduction**

1. Name of respondent: _____________
2. Education level__________________
3. Work experiences_________________
4. *Wereda* _________________________
5. *Kebele* _________________________

**Part II Guiding questions**

1. How do describe the trend of long-term changes in rainfall and temperature in your locality?
2. What variation did you observe about these changes in the last two decades?
3. What are the most frequently adverse shocks occurring that affect livelihoods?
4. How do you describe the influence these shocks on rural livelihood capitals?
5. Do you think your office deliver climatic information to farmers that would help adaptation strategies?
6. What do you think about the functions of informal and formal institutional arrangements to address the negative climate change impacts?
7. What are the major adaptation strategies used to address climate change risk impacts?

***Annex 1.4.*** Conversion factor of various classes of livestock to TLU

| Animal category | TLU |
|---|---|
| Calf | 0.25 |
| Donkey | 0.35 |
| Calf | 0.34 |
| Camel | 1.25 |
| Heifer | 0.75 |
| Goat/sheep | 0.13 |
| Cow and ox | 1.0 |
| Goats /sheep (young) | 0.06 |
| Horse | 1.1 |
| Donkey (Adult) | 0.7 |
| Chicken | 0.013 |

Source: Strock *et al*. (1991)

**Annex** 1.5: Conversion factor for Adult Equivalent (AE)

| | Sex | |
|---|---|---|
| Age groups (years) | Male | Female |
| <10 | 060 | 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 1.6:** VIF for variables used in the Heckman probit **outcome** model

| Variable | VIF | 1/VIF |
|---|---|---|
| Age | 1.58 | 0.6333 |
| Education | 1.33 | 0.7541 |
| Household size | 1.18 | 0.8510 |
| Livestock ownership | 1.44 | 0.6964 |
| Off farm activities | 1.25 | 0.7992 |
| Drought occurred last 10 years | 2.40 | 0.4162 |
| Farm land size | 2.74 | 0.3646 |
| Fertile plot size | 1.30 | 0.7713 |
| Receiving training at FTC | 1.18 | 0.8466 |
| Chemical fertilizer in quintal | 2.60 | 0.3848 |
| Distance to market | 1.57 | 0.6351 |
| Social networks | 1.41 | 0.7094 |
| Rainfall | 4.32 | 0.2315 |
| Temperature | 1.32 | 0.7555 |
| Mean VIF | **1.83** | |

**Annex** 1.7: VIF for variables used in the Heckman probit **selection** model

| Variable | VIF | 1/VIF |
|---|---|---|
| Age | 1.56 | 0.6419 |
| Education | 1.27 | 0.7851 |
| Household size | 1.12 | 0.8901 |
| Livestock ownership | 1.39 | 0.7181 |
| Drought occurred | *2.31* | *0.4322* |
| Farm land size | 2.73 | 0.3662 |
| Fertile plot size | 1.26 | 0.7948 |
| Receiving training at FTC | 1.16 | 0.8606 |
| Chemical fertilizer in quintal | 2.59 | 0.3857 |
| Distance to market | 1.50 | 0.6684 |
| Rainfall | 4.21 | 0.2376 |
| Temperature | 1.28 | 0.7821 |
| Mean VIF | **1.84** | |

**Annex** 1.8 contingency coefficient for dummy variables Heckman probit model

| Variables | Sex | AESs | CC information | AEZ *Dega* |
|---|---|---|---|---|
| Sex | 1.00 | 0.014 | 0.115 | 0.091 |
| AES | | 1.00 | 0.662 | 0.080 |
| CC information | | | 1.00 | 0.128 |
| AEZ *Dega* | | | | 1.00 |

**Annex** 1.9: VIF for variables used in the 3FGLS

| | VIF | 1/VIF |
|---|---|---|
| Age HH | 1.60 | 0.6269 |
| Education | 1.34 | 0.7457 |
| Dependency | 1.09 | 0.9173 |
| Size HH | 1.21 | 0.8271 |
| CBO | 1.44 | 0.6958 |
| Livelihood div | 1.24 | 0.8047 |
| Road | 1.80 | 0.5570 |
| Farm size | 2.66 | 0.3762 |
| Livestock | 1.59 | 0.6282 |
| Fertilizer | 2.71 | 0.3685 |
| Improved seed | 1.27 | 0.7877 |
| Irrigation potential | 1.08 | 0.9264 |
| Malaria exposure | 1.20 | 0.8337 |
| Flood | 1.15 | 0.8719 |
| Livestock death | 1.53 | 0.6537 |
| Energy | 1.07 | 0.9323 |
| Rainfal-Alitena | 2.75 | 0.3634 |
| Rainfall_Degamba | 4.42 | 0.2261 |
| Rainfall_Selam | 5.46 | 0.1832 |
| Mean VIF | **1.93** | |

**Annex** 1.10 contingency coefficient for dummy variables in 3FGLS

| Variables | Sex | credit access |
|---|---|---|
| Sex HH | 1.00 | 0.041 |
| Credit | | 1.00 |