IMPACTS OF CLIMATE CHANGE ADAPTATION PRACTICES ON SMALLHOLDER FARMERS' WELFARE IN THE BENCH MAJI ZONE, SOUTHWEST ETHIOPIA

PhD DISSERTATION

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This Dissertation is dedicated to my late uncle Admasu Belay and his wife Desta Kebede, and their true love for me was unforgettable.

STATEMENT OF THE AUTHOR

By my signature below, I declare and affirm that this Dissertation is my own work. I have followed all ethical and technical principles of scholarship in the preparation, data collection, data analysis and compilation of this Dissertation. Any scholarly matter that is included in the Dissertation has been given recognition through citation. This Dissertation is submitted in partial fulfillment of the requirements for a Doctor of Philosophy degree at the Haramaya University.

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BIOGRAPHICAL SKETCH

Andualem Begashaw Balamo was born in a village called Abaya, near Humbo City, in Southern Nations Nationalities and Peoples Regional State, in January 1982. He attended his elementary and secondary education in Abaya Elementary School and Arba Minch Kulfo Junior Secondary School, respectively. He attended his high school education in Arba Minch Comprehensive Secondary School. He graduated from Arba Minch University with a Bachelor of Arts degree in economics in 2008 and a Master's of Science degree in Development Economics from Ethiopian Civil Service University in 2014. He joined the Doctoral program in Haramaya University to pursue his PhD degree in Agricultural Economics in 2017

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ABBREVIATIONS AND ACRONYMS

ATA	Agricultural Transformation Agency
3FGLS	Three-step Feasible Generalized Least Square
BMZFEDD	Bench Maji Zone Finance and Economic Development Department
BMZFNRD	Bench Maji Zone Farm and Natural Resource Department
BMZADD	Bench Maji Zone Agriculture Development Department
CSA	Central Statistical Agency of Ethiopia
ECA	Economic Commission for Africa
FAO	Food and Agricultural Organization of the United Nations
FCEAE	Food Consumption Expenditure per Adult Equivalence.
FDRE	Federal Democratic Republic of Ethiopia
IFAD	International Fund for Agricultural Development
IPCC	Intergovernmental Panel on Climate Change
MEFCC	Ministry of Environment, Forest and Climate Change
MESRM	Multinomial Endogenous Switching Regression Model
METEM	Multinomial Endogenous Treatment Effect Model
MoFED	Ministry of Finance and Economic Development
MoPD	Ministry of Planning and Development
NBE	National Bank of Ethiopia
NMSAE	National Metrological Service Agency of Ethiopia
NOAA	National Oceanic and Atmospheric Administration
SNNPR	Southern Nations Nationalities and Peoples Region
UNEP	United Nations Environment Programme.

UNFCCC	United Nations Framework Convention on Climate Change
VFI	Vulnerability to Food Insecurity

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ABSTRACT

Climate change significantly impact smallholder farmers' welfare in agrarian economies like Ethiopia. The sustainability of agriculture relies on the farmer's ability to adjust their production systems in response to environmental and economic shocks and fluctuations. This study aimed to investigate the impact of climate change adaptation practices on smallholder farmers' welfare in the Bench Maji Zone, southwest Ethiopia. The research examined farmers' perceptions of climate change, their adaptations, factors influencing their choice of adaptation practices, and the impact of adopting single and combined adaptation strategies on farm income, downside risk, vulnerability to food insecurity, and the cost of risk. Cross-sectional data from 390 households in four climate-prone districts was collected using a standardized questionnaire, as well as rainfall and temperature data from 1989 to 2021. Data analysis involved the use of descriptive statistics and econometric models. The findings revealed that farmers understood climate-related changes and implemented various adaptation measures to mitigate risks. These strategies included crop diversification, soil and water conservation, improved varieties, and livelihood portfolio diversification. The multivariate probit model was employed to identify the factors determining farmer's choice of climate change adaptation strategies. The decision of the farming household to adopt crop diversification was positively influenced by frequent extension visits, access to climate information, and perceptions of moderate soil, while opinions of good soil and a moderate slope had a negative influence. Factors such as gender of the household head being male, farm size, distance from market, perception on the severity of erosion, and climate shocks positively affected soil and water conservation practices, while the perception of a flat slope had a negative influence. Education level, farm size, extension visits, access to climate information, climate shock, climate perception positively determined the adoption of improved varieties. At the same time, perceptions of good soil had a negative effect. Education level and climate shocks had a positive impact on livelihood portfolio diversification, while farm size and proximity to the market had a negative impact. A multinomial endogenous switching regression model was used to estimate the impact of adopting single and combined climate change adaptation practices on farm income and downside risk. When considering both *observed and unobserved differences related to individual and combined adaptation methods, farm households that use climate change adaptation techniques, either alone or in combination, tend to see increased farm income and a notable decrease in downside risk. Results from estimating the multinomial endogenous treatment effect model showed that implementing climate change adaptation strategies together effectively reduced vulnerability to food insecurity. A quantile moment approach was applied to estimate the cost of risk. The findings reveal that the risk premium for adopting any climate change adaptation techniques, whether alone or in combination, is lower than for non-adoption in the lowest quantile. These findings underscore the importance of implementing climate change adaptation strategies in agriculture to reduce susceptibility to food insecurity during uncertain climate events. Therefore, integrated strategies, particularly the comprehensive adoption of all three strategies is needed to enhance income stability amid climate variability.*

Key Words: Climate change; Smallholder farmers; Adaptation Decision; farm income; downside risk; Cost of risk; Multinomial endogenous switching; Bench Maji

1. INTRODUCTION

1.1. Background

Developing countries rely heavily on rain-fed agriculture, and most of the population's livelihood is directly or indirectly dependent on agricultural activities. Agricultural growth is also considered more pro-poor than industrial growth since it enables greater participation of low-income individuals in the growth process (World Bank, 2008; Xinshen *et al.,* 2010). Therefore, the sector is the key to poverty reduction and an economic development engine for most agrarian economies (Ellis, 1993; World Bank, 2008; De Janvry and Sadoulet, 2010; Jhingan, 2011). Nevertheless, this sector is particularly susceptible to the adverse effects of climate change, given its reliance on rainfed systems (IPCC, 2014).

Climate change and variability are the most vital worldwide threats affecting the agricultural sector. Notably, in developing countries, the agricultural sector is intrinsically sensitive to climate conditions. It is among the most vulnerable sectors to the adverse effects of climate change compared to the other sectors (Ayanwuyi *et al*., 2010). Africa has been recognized as one of the most susceptible continents to climate change effects (IPCC, 2014; Niang *et al*., 2014). Climate change will likely significantly stress agricultural production and the biophysical, political, and social systems that determine food security in Africa (Connolly and Smit, 2016). Mainly, in sub-Saharan Africa, the combined effects of climate change and associated factors, such as the limited ability to adapt financially and institutionally, will increase food insecurity and vulnerability of the people (Kurukulasuriya *et al.,* 2006; Bryan *et al.,* 2009; Juana *et al.,* 2013). Therefore, this situation makes adaptation strategies for climate change and variability an essential agenda item in Africa's sustainable agricultural production arena (Easterling *et al.,* 2007).

Many African countries increasingly take a national, strategic approach to preparing for climate change. For instance, the government of Ethiopia has made the necessary institutional arrangements and is taking steps to build a governance structure towards dealing with climate change, adaptation strategies, and interventions. The government developed a "Climate-Resilient Green Economy" (CRGE) strategy in 2011, which aims to keep greenhouse gas emissions low and build climate resilience while achieving middle-income status by 2025 (FDRE, 2011). The CRGE strategy aims to promote green growth and reduce the country's vulnerability to climate change by integrating climate change adaptation and mitigation measures into all economic planning and development aspects. This strategy includes measures such as promoting renewable energy, sustainable agriculture, and the efficient use of natural resources. Ethiopia's current 10-year perspective plan also emphasizes sustainable development and economic growth, focusing on increasing industrialization and improving infrastructure (Planning and Development Commission, 2020). By aligning the CRGE strategy with the goals of the 10-year perspective plan, Ethiopia can ensure that its economic development is environmentally sustainable and resilient to the impacts of climate change.

Ethiopia's economy and most people's livelihoods heavily rely on rainfed agriculture. This is highlighted by the fact that out of the total estimated agricultural area of 21.8 million hectares, only 1.11 million hectares are designated as irrigated areas. It indicates that irrigation has a minimal impact on the country's agricultural sector, as only about 5% of the total agricultural area is irrigated (Dawit *et al.,* 2022; Chandrasekharan *et al.,* 2021). Therefore, this sector is highly susceptible to the adverse effects of climate change and variability. Notable production losses stemming from erratic and unpredictable rainfall, land degradation, pests, and diseases have significantly diminished food security for households and undermined their purchasing power. As a result, many are compelled to resort to harmful coping strategies, such as selling their remaining agricultural assets and migrating (FAO, 2016; FAO and ECA, 2018).

Various reports have shown that the average yearly temperature in Ethiopia rose by 1.3°C from 1960 to 2006 and is expected to rise by 1.1 to 3.1°C by the 2060s and 1.5 to 5.1°C by the 2090s (Irish Aid, 2018; The World Bank Group, 2021; Richardson *et al.*, 2022). Given the ongoing rise in temperatures and fluctuations in precipitation, it is expected that there will be a rise in extreme weather events, necessitating thorough adaptation strategies. Moreover, climate model projections of climate over Ethiopia show annual warming of 2.2°C with a range of 1.4–2.9°C by the 2050s in all four seasons across the country but a wide range of rainfall patterns (Conway and Schipper, 2011; McSweeney *et al*., 2010). This is expected to impact crop productivity negatively. Furthermore, the rising temperature may create a favorable environment for the prevalence of new pests, weeds, and diseases that harm crops and livestock production (Pereira, 2017). Many previous studies (Yesuf *et al*., 2008; Emerta, 2013) also stated that Ethiopia lost over 13 percent of its agricultural output between 1991 and 2008 due to a 13.38-millimeter average rainfall decline per year. If this decline in the average annual rainfall continues, Ethiopia will forgo more than six percent of each year's agricultural output (Emerta, 2013). These climate changes have also had significant impacts on smallholder farmers in southwest Ethiopia, leading to decreased crop yields, increased pest and disease outbreaks, and reduced income and food security (BMZFNRD, 2018).

Historical and future climate trends significantly influence Ethiopia's susceptibility to climate change and its ability to adapt (Echeverría and Terton, 2016). The adverse effects of climate variability and extremes on agricultural production are particularly pronounced, underscoring the need to implement mitigation strategies and adopt specific adaptation technologies. Adapting to climate change necessitates the enhancement of systems' capacity to manage exposure and sensitivity to climate hazards and to withstand adverse impacts (USAID, 2007).

Bench Maji, one of the zones in the southwest Ethiopia regional state located in the southwest of the country, has suffered from climatic-induced shocks, such as a shortfall in food production because of prolonged and recurrent floods, dry spells, pests and diseases, and other related factors. Given the impact of climate change and variability on agriculture, smallholder farmers and local governments in the study area are adopting various adaptation strategies and coping mechanisms to address extreme weather events. The strategies involve soil and water conservation methods like stone bunds, soil bunds, and terraces, crop management techniques such as crop diversification and utilizing drought-resistant crop species, and diversifying livelihoods through on-farm, non-farm, and off-farm activities (BMZFNRD, 2018). While these efforts have been made to improve the ability of smallholder farmers to adapt their production systems to environmental and economic shocks, there has been no detailed investigation of the impacts of these measures on the household's welfare so far. Overlooking such kinds of studies limits informed policy formulation on adaptation strategies and confines the identification and development of practical means for enabling communities to reduce vulnerability at various levels.

Given that climatic factors are key determinants of agricultural productivity in many low-income countries, including Ethiopia (Apata *et al.,* 2009), it is natural for research to focus on understanding the effects of climate change adaptation measures on the welfare of households. This is particularly relevant for addressing rural poverty and food security challenges. Consequently, this study represents the first effort to estimate the welfare impacts of climate change adaptations among smallholder farmers in the Bench Maji zone of southwest Ethiopia. It involves identifying the primary adaptation practices utilized by farmers and examining the factors that influence their decisions to adapt. Therefore, this study is the first attempt to estimate the welfare impacts of adaptations to climate change and variability on smallholder farmers in the Bench Maji zone, southwest Ethiopia. It involves identifying the main adaptation practices of farmers and examining the factors that influence their adaptation decisions.

1.2. Statement of the Problem

It is widely agreed upon that the global climate has undergone significant changes and will continue to do so. The IPCC's Sixth Assessment Report (AR6) offers vital information about the physical science underpinnings of climate change. According to the report, human activity raised the average global surface temperature during the pre-industrial era. From 1850–1900 to 2010–2019, the global surface temperature has increased by 0.8°C to 1.3°C, with the most accurate estimate being 1.07°C (IPCC, 2021). It is crucial to comprehend the far-reaching impacts of global warming on the delicate balance of the planet's climate and environmental systems. Rising temperatures due to climate change are expected to significantly impact weather patterns, increasing the frequency and intensity of severe weather events such as droughts, storms, and floods (IPCC, 2014; NOAA, 2020; IPCC, 2021). Additionally, ripple effects could include disruptions in ocean currents, altered rainfall patterns, and a worrisome rise in sea levels (Zhai and Zhuang, 2009). Several studies indicate that agriculture production could be significantly impacted due to increase in temperature (Aggarwal *et al.,* 2009; Lobell *et al.,* 2012), changes in rainfall patterns (Prasanna, 2014) and variations in frequency and intensity of extreme climatic events such as floods and droughts (Brida and Owiyo, 2013; Singh *et al.,* 2013). Several studies indicate that agriculture production could be significantly impacted due to increase in temperature (Aggarwal et al., 2009; Lobell et al., 2012), changes in rainfall patterns (Prasanna, 2014) and variations in frequency and intensity of extreme climatic events such as floods and droughts (Brida and Owiyo, 2013; Singh et al., 2013). However, the impacts of global climate change are felt differently across the world, with developing countries bearing the brunt due to their limited capacity for climate change adaptation, technology, and resources (FAO, 2011; Emerta, 2013). This underscores the urgent need for effective adaptation strategies and policies to mitigate the impacts of climate change on farmers' welfare and food security.

Ethiopia is one of the most vulnerable countries to the adverse effects of climate change and extremes, such as widespread shifts in rainfall amounts, extreme floods, droughts, and plant and animal diseases (Müller *et al.,* 2014; Hertel *et al.,* 2014; Amsalu *et al.,* 2018). The agriculture sector, which accounts for more than 33.7% of the GDP, 86% of the annual foreign exchange earnings, and 65% of the employment of the Ethiopian economy (NBE, 2019; World Bank, 2019), it is one of the most vulnerable sectors to the current and projected climate change, potentially exposing millions of people to recurrent food shortages (ATA 2017). There is also a broad consensus in the scientific literature that climate variability and associated droughts, as well as the poor status of market fundamentals and agricultural services such as extension and credit, among others, have been significant causes of food insecurity and famine in Ethiopia (Arragaw and Woldeamlak, 2016; Walter *et al.,* 2017). Furthermore, studies on the link between climate change and agriculture revealed that climate is Ethiopia's primary determinant of agricultural production and productivity (Temesgen *et al.,* 2011; Sintayehu *et al.,* 2017).

The study area, Bench Maji Zone, mainly has three livelihood systems: sedentary farming, agropastoral, and pastoral. Most smallholder farmers in the zone depend on rain-fed agriculture and pasture, making them particularly vulnerable to drought, livestock disease, and crop pests (BMZFNRD, 2017). There is a high level of forest coffee production in the study area, along with spices collected from the forest for the market. However, deforestation and soil degradation have become more worrisome (SNNPR, 2005). Moreover, a wide range of biotic and abiotic stresses constrain field crop production in the zone. The latest report (2017) from the Farm and Natural Resource Department of Bench Maji Zone presents concerning findings regarding the agricultural sector. The report reveals that a total of 265.5 hectares of farmland, which produced essential crops such as wheat, teff, barley, and inset, were severely impacted by a range of pests and diseases. This data underscores the pressing need for more effective pest and disease management strategies to safeguard farmers' livelihoods and ensure food security for the local population.

Smallholder farmers in the study area, particularly those engaged in maize production, face unique challenges. Moreover, in 2017, the Fall Armyworm (FAW) infested 404.8 hectares of maize across five districts in the zone (Fenta, 2018; BMZFNRD, 2017). Over 200 households in the Bench Maji Zone have been displaced since 2015, primarily due to heavy rains that led to flash floods (BMZFNRD, 2017). As a result, households' ability to engage in their typical livelihood activities, such as seasonal cultivation and rearing of livestock, has been enormously affected, hence escalating the humanitarian crisis in the study areas.

Several studies have also revealed that climate can affect livestock by either directly impinging on animal growth, animal products, and reproduction or indirectly influencing the quantity and quality of feedstuffs such as pasture, forage, grain, and the distribution of livestock diseases and parasites (Seo and Mendelsohn, 2006). Accordingly, very few studies (Tesfaheywet and Simeon, 2013) have indicated that ruminants in the Bench Maji zone were infested with various ectoparasites, impacting the animals' productivity, farmers' economies, and the country as a whole.

The problem of climate change and its impact on agriculture in Ethiopia is an urgent issue that demands immediate attention. Studies have shown that the sustainability of agriculture in the country is dependent on farmers' ability to adapt to environmental and economic shocks (Temesgen *et al.,* 2011). However, those with the least capacity to adapt will face increasing financial losses over time. Despite efforts to implement adaptation strategies, there has been a lack of investigation into the effects of these measures on the welfare of rural households. It is crucial to address this gap in research in order to better support smallholder farmers in adapting to changing climatic conditions and ensuring the long-term viability of agriculture in Ethiopia.

Research on smallholder farmers' perceptions of climate change and their adaptation strategies can be categorized into four primary methodological approaches. The first category employs the Heckman sample selection probit model to analyze farmers' perceptions and adaptation practices (Solomon *et al.,* 2016; Paulos and Belay, 2018; Waibel *et al.,* 2018). While effective in identifying significant factors, this approach aggregates all adaptation practices into a single category, limiting its ability to analyze the diverse strategies influenced by various factors (Piya *et al.,* 2013).

The second category utilizes univariate techniques like probit or logit analysis to investigate adaptation choices (Menike and Keeragala, 2016; Keneilwe and Phatsimo, 2018; Hurgesa *et al.,* 2020). However, these methods often overlook correlations among unobserved disturbances, missing crucial dynamics in farmers' decision-making processes (Golob and Regan, 2002). The third category employs the multinomial logit (MNL) model to explore the factors influencing various adaptation practices (Alem *et al.,* 2016; Abayneh and Belay, 2017; Amogne *et al.,* 2017; Makate *et al.,* 2019). A key limitation of the MNL model is its assumption that practices are mutually exclusive, which does not reflect the reality of concurrent strategy adoption (Piya *et al.,* 2013).

The fourth category advances the analysis using the multivariate probit (MVP) technique, allowing for simultaneous modeling of multiple adaptation options (Piya *et al.,* 2013; Wondimagegn and Lemma, 2016; Ojo and Baiyegunhi, 2019). This study also employs an MVP model, which addresses the limitations inherent in previous methodologies by permitting the simultaneous modeling of the probabilities of selecting multiple adaptation options based on explanatory variables. In doing so, it effectively accounts for the correlations among choice variables, thus providing a more nuanced understanding of the factors influencing farmers' adaptation strategies.

Up to now, far too little attention has been paid to analyzing the impacts of different adaptation strategies to climate change and variability on farmers' welfare in a rigorous fashion. Few studies focus on analyzing single or individual adaptation practices. For example, Fissha *et al.* (2019) have examined the effects of crop diversification as a climate change adaptation strategy, on-farm household welfare concerning farm income, and demand for labor in the Nile basin of Ethiopia. Despite its immense contribution to boosting the understanding of drivers to adaptation and its implications for the welfare of farmers, it is considered only a single adaptation strategy. Intuitively, however, farmers are faced with strategies that can be adopted as complements, substitutes, or supplements to deal with the adverse effects of climate change and variability. Therefore, ignoring the likely interrelationships between the various strategies in adoption and impact analysis may lead to biased conclusions (Yu *et al.,* 2011).

Few studies have assessed the impact of adaptation practices on farmers' welfare, considering a mix of different adaptation strategies (Di Falco and Veronesi, 2013; Melaku *et al.,* 2017). A study by Di Falco and Veronesi (2013) analyzed the impact of different adaptation strategies on net crop revenue in the Nile basin of Ethiopia. Although their study considers different adaptation strategies, it is also highly aggregated and has little significance for considering particular area adaptations to climate change. In addition, the study was conducted over a decade ago, which may not reflect the ever-changing impact of climate change on farmers' adaptation decisions, which have likely altered dramatically over time. Moreover, this study failed to evaluate the effect of adaptation practices on the cost of risk, a significant concern in uncertainty about global environmental change (UK, 2012). These limitations highlight the need for more comprehensive and up-to-date research in this area.

A study by Melaku *et al.* (2017) also investigated perception and adaptation to climate change and whether these practices have improved the farm income of different communities in the Afar region. However, the Afar communities' livelihood strategies and adaptation practices differ from Bench Maji's. Hence, not considering this variation of adaptation strategies and even adaptive capacities contextually and spatially may lead to an erroneous conclusion about the effects of the strategy (Smit and Wandel, 2006). Moreover, the study analyzed how adaptation techniques affect household income levels. While income is an important indication, it may not reflect other aspects of well-being, such as food security and general resilience. Furthermore, the study implies that adaptation techniques connected to long-term income benefits can help address climate change. However, assumptions concerning the long-term viability of these techniques should be carefully scrutinized.

Against this backdrop, this study intends to address the shortcomings mentioned earlier in two ways. First, the study links farmers' different adaptation practices with household welfare regarding farm income, risk exposure, and vulnerability to food insecurity. This offers micro-level evidence about the factors affecting the choice of adaptation strategies and how these adaptations impact farm income, risk exposure, and vulnerability to food insecurity. Secondly, the study evaluates the welfare implications of the ongoing adaptation strategies by measuring the cost of risk. Therefore, this study contributes significantly to the existing literature on the impact analysis of adaptation strategies for climate change and variability in the following ways: It primarily explores the welfare effects of single and combined adaptation practices of climate change and variability. This would benefit not only a better understanding of farmers' adaptation behaviors to changes in climate and variability but also provide empirical evidence for policymakers in the development of adaptation strategies for the agricultural sector at the micro level. Moreover, it helps design context-specific donor-funded projects and programs by development and international research organizations.

1.3. Research Questions

The study aimed to address the following specific research questions:

1. Do farmers perceive changes in climatic parameters and what adaptations have they employed against climate change impacts?
2. What are the determining factors that influence farmers' choice of adaptation practices to climate change and variability?
3. What is the impact of adopting single and combined climate change adaptation practices on farm income, downside risk, and vulnerability to food insecurity?
4. What is the impact of adopting single and combined climate change adaptation practices on the cost of risk?

1.4. Research Objectives

The main objective of the study is to empirically assess and analyze the impact of different adaptation strategies on farm household welfare in Bench Maji zone, southwest Ethiopia. More specifically, this study addresses the following objectives;

1. To assess farmers' perception of changes in climatic parameters and identify specific adaptations employed by farmers to mitigate climate change impacts.
2. To determine the factors that influence farmers' decision-making process in choosing specific adaptation practices to climate change and variability.
3. To evaluate the impact of adopting single and combined climate change adaptation practices on farm income, downside risk, and vulnerability to food insecurity.
4. To assess the cost implications associated with adopting single and combined climate change adaptation practices, with a focus on estimating the cost implications of reducing downside risks.

1.5. Scope and Limitations of the Study

The scope of this study is limited conceptually, geographically, and in terms of participants. Conceptually, it is focused on exploring factors that determine farmers' choices of adaptation strategies and estimating the impact of these strategies on farm households' welfare and their link with the costs of risk. This is achieved through a unique combination of a multinomial endogenous switching regression model, a multinomial endogenous treatment effect, and a quantile-based moment risk analysis approach. Although adaptation encompasses various types of action, this study is highly focused on autonomous or reactive adaptation strategies practiced by smallholder farmers. Geographically, the study focused on the Bench Maji zone in southwest Ethiopia. The level of analysis for this study is farm households, where micro-analysis of farm income, exposure to risk, vulnerability to food insecurity, and the cost of risk from adaptation is analyzed to find the impact of strategies on improving farmers' welfare. It is also bounded for households that are smallholder farmers, although there are few commercial farms in the study area. Though some land fertility indicator variables are used in the study, it is important to note that these variables' effects are best seen when plot-level data is examined as opposed to data from farm households.

The study has limitations in its external validity; therefore, generalizing it should be done with caution. Nevertheless, this study argues that many smallholder farmers in rural Ethiopia suffer similar socioeconomic and institutional challenges. The adaptive techniques and constraints they face are not unique to this specific group but are akin to those encountered by other smallholder farmers in Ethiopian agroecology. This shared experience underscores the importance of this research in understanding and addressing these challenges. Since this study partly depends on cross-sectional data, it is limited to showing the time effects of various climate change adaptation strategies on the farm household's income and vulnerability to food insecurity. Another primary source of uncertainty would be the variable farm income analysis. Exceptionally, a comprehensive determination of hidden costs and expenses will indeed be challenging because of the existence of hidden fees. Despite the wide use of the endogenous switching regression model for impact analysis, it usually requires at least one variable in the treatment equation to provide an instrument for specifying the outcome equation. However, finding such instruments remains a challenging task in empirical analysis. The other limitation of the study was also attributed to the season it covers (only one agricultural season and does not consider seasonal food security changes within a given year). Moreover, measuring vulnerability to food insecurity solely based on the amount of money required to achieve the daily minimum dietary requirement does not consider the non-income factors that influence food security, such as availability, utilization, and stability of food supply, as well as social, cultural, and environmental factors (Napoli *et al.,* 2011). Food security is a complex interplay of various factors, including economic, social, and environmental elements. For example, Amartya Sen's work emphasizes that food access is determined by entitlements, which are influenced by factors beyond income, such as social status and local food systems (Jones *et al.,* 2013). This complexity suggests that a singular focus on monetary measures can overlook critical barriers to food security.

1.6. Significance of the Study

Research on the impact of adaptations to climate change and variability on farm households' welfare is necessary, especially for smallholder farmers, who depend more on natural resources and the environment for their livelihood. Studies on climate change have shown that smallholder farmers in Ethiopia are adversely affected by the change in climate and variability because antagonistic climate change reduces crop productivity, livestock, and fish production. Adaptation, therefore, remains one of the policy options to address climate challenges. Consequently, the nature and magnitude of climate change adaptation strategies on farm households' welfare, the perceptions of climate change, and adaptation choices made by farmers are essential considerations in the design of adaptation strategies by policymakers and agricultural extension services.

The study may provide important information to policymakers and agricultural extension services, which would improve their understanding of the farmers' interpretation of climate change and the constraints that have prevented them from undertaking more and better adaptation measures. This understanding will, in turn, help to guide policymakers on ways to promote adaptation and develop a better participatory plan for climate change and variability. Articulating an understanding of climate change and variability empowers policymakers with the essential tools needed to craft adaptive, participatory, and effective strategies for tackling the complex challenges posed by these phenomena. As highlighted by Pahl-Wostl (2009), adaptive management that incorporates stakeholder participation is crucial for developing strategies that are resilient and dynamic, adapting to new information and changing conditions. This approach underscores the importance of adopting a holistic strategy that addresses the unique needs of diverse communities. Moreover, the study result will also benefit nongovernmental organizations (NGOs) and donor countries engaged in development activities by providing location-specific information. This information may affect their development intervention approach. Furthermore, since risks are more related to weather variability and there are limited risk management strategies in the study area, the analysis of the link between adopting adaptation strategies for climate change and variability and the cost of risk provides holistic and considerable evidence in the agricultural policy-making process.

1.7. Organization of the Dissertation

The remaining part of the paper proceeds as follows: Chapter Two begins by laying out the theoretical dimensions of the research and looks at climate change, its causes, relationships with agriculture, adaptation options, methodological reviews, and related empirical studies on the impact of adaptations to climate change. It also presents a conceptual framework for the study, which shows a typical farm household's adaptation behavior in response to climate-related shocks and the impact of adaptations.

The third chapter is concerned with the research design and methodology adopted for the study in terms of the sampling procedure, data collection instrument, methods of analysis, specification of the econometric model, and definition of variables. Chapter four analyses the data gathered and addresses each research question in turn. The descriptive statistics results and regression outputs were thoroughly discussed so that meaningful conclusions could be drawn. The final chapter summarizes and concludes the study's main findings in light of the research questions and objectives set out in Chapter 1. The chapter also outlines recommendations and presents suggestions for future research.

2. LITERATURE REVIEW

The review of related literature is structured into five sections. First, an attempt is made to discuss key concepts and terminologies of climate change and variability relevant to this study, including the causes of climate change, explaining the relationship between climate change and agriculture, and identifying adaptation options in agriculture to climate change. The second part highlights the workable economic theory that guides the topic of the study. The third section provides detailed information about the specific methods used in the research and analyses, such as data collection through surveys and interviews, and statistical analysis using regression models. The fourth section reviews the local and overseas studies conducted on this topic, summarizes all the discussions, and draws implications for the present research. The final section of the review presents a conceptual framework that depicts the adaptation behavior of typical farm households in response to climate-related shocks. The framework is built upon the institutional analysis and development (IAD) framework.

2.1. Definitions and Basic Concepts

2.1.1. Definition of Climate Change

Without much change in the basic concepts, different organizations define climate change in different ways. According to the UNFCCC (1992), climate change is defined as a change in climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and is in addition to natural climate variability observed over comparable periods. However, this explanation puts more emphasis on those human activities that change the composition of the global atmosphere and excludes other human activities like agricultural activities, and other land uses such as deforestation.

The definition of climate change has been a matter of ongoing discussion among international organizations. IPCC (1998) also defines climate change as a significant shift in the average weather condition, especially the average temperature and precipitation of an area. However, this definition overlooks the prime causes and effects of climate change. By incorporating the sources of climate change, the IPCC (2007) report redefined climate change as a change in the state of the climate that can be identified (e.g., using statistical tests) by changes in the mean and the variability of its properties and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity. Following WHO (2003), UNFCCC (2007), and IPCC (2007), climate change in this study is defined as a statistically significant shift in average climate and its variability, typically decades or longer, due to natural processes and anthropogenic activities that affect the environment and the wellbeing of a human being.

2.1.2. Climate Variability

Sometimes, the term 'climate change' is used to include all climate variability, which can lead to considerable confusion. It's important to note that climate has variability on all time and space scales. It will always be changing (David, 2002). Climate variability is the term used to describe changes in the average conditions and other statistical properties (standard deviations, the occurrence of extremes, etc.) of the climate over a certain period and beyond those of individual weather events. This is different from climate change, which refers to long-term shifts in temperature and precipitation patterns.

Variability may result from natural internal processes within the climate system (internal variability) or variations in natural or anthropogenic external forces (external variability) (IPCC, 2001). Solar radiation and volcanic activity, these natural phenomena that are beyond our control, are significant causes of climate variability. However, as the IPCC stated in 2001, human activity is to blame for the changes in the atmosphere's composition since the Industrial Revolution, reminding us of the delicate balance we disrupt with our actions (IPCC, 2001).

2.1.3. Weather

Weather is the current atmospheric condition in a given place and the short-term state of the atmosphere (from hours to a few weeks), with variations such as temperature, humidity, precipitation, cloudiness, visibility, or wind. To sum up, the weather is what is happening now or is likely to happen tomorrow or very shortly (USAID, 2007).

2.1.4. Climate Change Vulnerability

Climate change vulnerability (in the context of this study) refers to both physical vulnerability (exposure to climate hazards) and social vulnerability (sensitivity to climate risks) due to the adverse effects of climate change, including climate variability and extremes. Anita *et al.* (2010) say that a system's vulnerability depends on the type, amount, and rate of climate change it faces compared to how sensitive it is and how well it can adapt.

2.1.5. Perception of Climate Change

Perception is a complex and dynamic process through which individuals interpret the world around them based on their senses and previous experiences. In general, perception involves the selection, organization, and interpretation of information from the external environment (Wossink and Boonsaeng, 2003). Hence, perceptions of climate change refer to a farmer's aggregate knowledge, attitudes, or beliefs about climate change and variability. Nzeadibe (2011) stated that perceptions of climate change can shape farmers' preparedness to adapt, change, or modify their farm practices.

2.1.6. Adaptation to Climate Change

Researchers in developing and developed countries document many definitions and characteristics of adaptation (Smit *et al.,* 2000; Burton *et al.,* 2005). However, the concept of adaptation varies with the range of fields. By distinguishing between different types of adaptation, Stakhiv (1994) defined adaptation as any adjustment, whether passive, reactive, or anticipatory, that is proposed as a means of facilitating the anticipated adverse consequences associated with climate change. According to Smit *et al.* (2000), adaptation is an adjustment in ecological, social, and economic systems in response to actual or expected climatic stimuli, their effects, or impacts. Along similar lines, the IPCC (2001) defines adaptation as the process by which natural or human systems adjust in response to current or anticipated climatic stimuli or their impacts, effectively mitigating harm and capitalizing on opportunities.

As per the UNFCCC (2007), adaptation involves societies enhancing their ability to deal with an uncertain future. This framework emphasizes that adapting to climate change means taking proactive measures to mitigate negative impacts and capitalize on any positive outcomes through appropriate adjustments and changes. Additionally, Adger *et al.* (2007) define adaptation to climate change as a response involving adjustments in natural or human systems to either minimize harm or take advantage of beneficial opportunities stemming from climatic stimuli. In contrast, Smit and Wandel (2006) regard adaptation as a dynamic process within various systems at different levels, such as households, communities, or countries, aimed at effectively managing changing conditions, risks, or opportunities.

In general, the definitions given here have much in common. All the definitions mentioned implied that adaptation involves building adaptive capacity, thereby increasing the ability of individuals, groups, or organizations to adapt to changes, making adjustments to decrease vulnerability, and implementing adaptation decisions (IPCC, 2001; Anita *et al.,* 2010). However, there are differences in the scope, application, and interpretation of the word adaptation. As a result, the various capacities and skills, asset base, and livelihood experiences among rural households' influence adaptation. Thus, in this study, adaptation strategies refer to a wide range of actions in response to the adverse effects of climate change that foster the adaptive capacity of smallholder farmers by reducing the marginal effect of climate change on productivity.

2.1.7. Adaptive Capacity

Adaptive capacity refers to the capability of systems, institutions, individuals, and other organisms to effectively recalibrate in the face of potential harm, seize upon new possibilities, or effectively address the outcomes of their actions (IPCC, 2014). In this context, improving the adaptive capacity of the system, region, or community reduces vulnerability and promotes sustainable development (Munasinghe, 2000). However, adaptive capacity is context-specific and varies from country to country, community to community, among social groups and individuals, and over time. It differs not only in terms of its value but also in terms of its nature (Smit and Wandel, 2006).

2.1.8. Forms of Adaptation

Before discussing forms of adaptation in the context of climate change and variability, it is essential to clarify why adaptation is vital. Smit *et al.* (2000) set two distinct but not independent reasons why adaptation is essential when considering climate change and variability. First of all, various adaptations can change the effects of climate change, no matter how severe or dangerous they are. Secondly, adaptation is considered a vital policy option or response strategy to concerns about climate change. Studies show that adaptation to global climate change is usually problematic for agricultural production, economies, and communities. However, with adaptation, the vulnerability can be reduced, and numerous opportunities can be realized (Mendelsohn, 1998). The IPCC (2001) maintains that adaptation can significantly reduce vulnerability to climate change by making rural communities better able to adjust to climate change and variability, moderating potential damage, and helping them cope with adverse consequences. Similarly, in Article 4.1 of the UNFCCC (2009), all participating parties have committed to creating, collaborating on, and executing initiatives to enable effective adaptation to climate change impacts. The Kyoto Protocol (Article 10) also commits parties to promote and facilitate adaptation and deploy adaptation technologies to address climate change (FAO, 2008).

Smit *et al.* (1999) categorized adaptations as autonomous or planned, anticipatory or responsive, short-term or long-term, and localized or widespread based on their purposes, timing, temporal scope, and spatial scope. Adaptation to climate change takes place in response to impacts already experienced and in anticipation of expected impacts. In this sense, adaptation can be a spontaneous, autonomous process that takes place depending on adaptive capacity and can also be planned. Autonomous adaptations occur in response to climate change without public intervention. To this end, it implies the use of current knowledge and techniques already available to respond to changes in climate that are already occurring. Most people think of autonomous adaptations as actions taken by private individuals rather than governments. According to Pittock and Jones (2000) and the IPCC (2001), they are frequently the result of changes in the economy or people's well-being due to actual or anticipated climate change. On the other hand, planned adaptation is typically seen as the outcome of a thoughtful decision made by a public agency, recognizing the need to respond to imminent or current changes in order to mitigate potential losses or take advantage of new opportunities.

Adaptations in agriculture can vary in scale and in terms of the entities responsible for their development and implementation. Different scales at which adaptations occur include the plant, plot, field, farm, region, and nation (Smit and Skinner, 2002). Additionally, the responsibility for implementing these adaptations in agriculture can be attributed to various actors, including individual producers such as farmers., agri-businesses (private industries), and governments (public agencies) (Smit *et al.,* 2000).

Adger *et al.* (2007), in a discussion of the fourth assessment report of the IPCC, identified two dimensions of what constitutes adaptive capacity, namely, the generic and impact-specific dimensions. Economic growth, education, technology, knowledge, infrastructure, institutions, fairness, and social capital affect a system's ability to adapt (Adger *et al.,* 2007; Jones *et al.,* 2010; Kruse *et al.,* 2013). At the same time, the impact-specific dimension of adaptive capacity is concerned with the ability of the system to respond to a particular climate change stimulus. Schneiderbauer *et al.* (2013) suggested a third dimension of adaptive capacity: the sector-specific dimension. This dimension is about how well a particular economic sector in a model region can adapt to the overall effects of climate change. In this dimension, social capital tends to determine the ability of local farmers to access labor resources.

Bradshaw *et al.* (2004) have attempted to identify some essential adaptation options in the agricultural sector. These are cropping diversification, mixed crop-livestock farming systems, using different crop varieties, changing planting and harvesting dates, and mixing less productive, drought-resistant varieties with high-yield, water-sensitive crops. However, the main weakness of this explanation is the failure to address the effects of institutions and irrigation systems on adaptation exclusively.

Some analysts (Orindi and Eriksen, 2005; Adger *et al.,* 2003) have shown that agricultural adaptation critically comprises diversification and crop management practices in production systems. The former involves engaging in production activities that are drought-tolerant or resistant to temperature stresses, as well as activities that make efficient use of and take full advantage of the prevailing water and temperature conditions, among other factors. Crop diversification provides insurance against rainfall variability since different crops are affected differently. On the other hand, the latter focuses on preventing crucial crop growth stages from overlapping with extreme weather conditions, such as mid-season droughts. Techniques such as adjusting the duration of the growing season and altering planting and harvesting schedules can be implemented to optimize crop management practices.

Overall, the available works of literature confirm that the key elements of adaptive capacity ensure the active involvement of individuals, communities, and societies in the process of change. Remarkably, this relates to changes in behavior, resources, and technology.

2.1.9. A Smallholder Farmer

A smallholder farmer is an individual or family-run agricultural producer who typically operates on a small scale, tending to livestock, cultivating crops, or engaging in fish farming. These farmers often rely on the labor of family members to manage their operations (Cousins, 2010). According to the CSA (2021) characterization, smallholder farmers in Ethiopia typically cultivate less than 2 hectares of land. They engage in mixed farming, involving both crop production and animal husbandry, and heavily rely on family labor for agricultural tasks. Due to their limited access to modern agricultural inputs, technology, and extension services, their output is primarily for subsistence, with a minimal surplus for commercial purposes. Additionally, the CSA (2021) report highlighted that Ethiopian smallholder farmers are particularly susceptible to external shocks such as market fluctuations, diseases, pests, and climate variability.

2.1.10. Downside Risk, the Cost of Risk, and Agriculture

Downside risk in agriculture refers to the asymmetrical distribution of risk, often skewed towards lower values, which is a common occurrence in agricultural production (Bardhan and Mookherjee, 2010). Average temperature and rainfall are critical determinants of agricultural yield, and deviations from optimal conditions can significantly impact farm productivity and, consequently, farm income (Lobell *et al.,* 2011). In such contexts, the distribution of yields tends to be biased towards lower values, with the likelihood of experiencing yields below the normal seasonal average being considerably higher than the probability of achieving above-average yields (Mastrorillo *et al.,* 2016).

Agricultural production is inherently fraught with uncertainties, as decisions made by farmers are often associated with multiple potential outcomes, each carrying different probabilities (Benedict *et al.,* 2018). Factors such as weather variability, market fluctuations, and unforeseen events are beyond a farmer's control, yet they exert a significant influence on the returns from farming (Davis *et al.,* 2017). Understanding these dynamics is crucial for developing effective risk management strategies that can help farmers mitigate the adverse effects of downside risk in agricultural production.

The cost of risk associated with downside risk in agriculture is a significant concern, particularly as climate change exacerbates the challenges faced by farmers. Downside risk refers to the potential for losses or adverse outcomes, which can stem from various sources including unpredictable weather patterns, pest outbreaks, and market fluctuations (Kim *et al.,* 2014). For example, studies have shown that extreme weather events, intensified by climate change, can lead to substantial yield losses, threatening food security and farmers' livelihoods (IPCC, 2021). According to a report by the Food and Agriculture Organization (FAO), climate-related risks could reduce agricultural productivity by up to 30% in some regions by 2050, increasing the cost of risk management strategies for farmers, which may include crop insurance and investment in resilient practices (FAO, 2020).

To manage these growing risks, climate change adaptation strategies become essential for farmers and agricultural stakeholders. Such strategies encompass a wide range of practices aimed at enhancing resilience to the changing climate. These may include the adoption of climate-smart agriculture techniques, such as drought-resistant crop varieties, improved irrigation systems, and agroforestry. For instance, research from the World Bank indicates that investing in sturdy infrastructure and sustainable practices can significantly reduce the vulnerability of farming systems (World Bank, 2019). Additionally, farmers may pursue diversification of crops and income sources, which not only mitigates downside risk but can also enhance overall farm productivity.

Furthermore, implementation of robust policy frameworks is critical to support adaptation strategies in agriculture. Governments and organizations can play a pivotal role by providing financial assistance, access to technology, and educational resources that empower farmers to adopt best practices in response to climate change. To illustrate, initiatives like the Green Climate Fund aim to channel funding towards sustainable agricultural projects that promote resilience (Green Climate Fund, 2021). Collaborative approaches, involving public-private partnerships, are also essential to share knowledge and resources effectively. As climate change continues to impose significant costs of risk on agricultural systems, the integration of adaptive strategies is not only a necessity but a strategic imperative for ensuring food security and economic stability in the face of uncertain futures.

2.1.11. Concepts of Food Security

The first serious discussions and analyses of food security emerged during the first world food conference which was held on 1974s for the period of global food crisis took place. In this episode food security is defined as availability at all times of adequate world food supplies of basic foodstuffs to sustain a steady expansion of food consumption and to offset fluctuations in production and prices (Clay 2002; Maxwell and Frankenberger, 1992). At this time the concept of food security is highly interrelated with food supply i.e. the accessibility of food and, in some extent; the price steadiness of basic food staffs at the international and national level (FAO, 2005). However, such explanations tend to overlook the fact that food security is a pervasive concept, encompassing a lot of ideas and which has persistently incorporated new dimensions and levels of analysis over the years. Later, World Bank (1986) defined food security as access by all people at all times to sufficient food for an active and healthy life.

The USAID (1992) defined food security as a situation achieved when all people at all times have both physical and economic access to sufficient food to meet their dietary needs for a productive and healthy life. This view is supported by World Summit on Food Security (1996) and FAO *et al.* (2018) which defined as food security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life. When these conditions are not meet, people are referred to as being food insecure (Woller, *et al.,* 2013). From this definition, food security has that four key components or dimensions namely food availability, food accessibility, food utilization, and food stability (Tandon *et.al.,* 2017)

Food availability which can be simply defined as the physical presence of food to households whether it is from own production (like farm, garden) or market (Chen *et al.,* 2018). A more detail meaning of food availability can be found in the definition given by USAID (1992). Accordingly, it is defined as when "sufficient quantities of appropriate, necessary types of food from domestic production, commercial imports, commercial aid programs, or food stocks that are consistently available to individuals or within their reach". Other determining factors of food availability include but not limited to macroeconomic trends, government policies, functioning international and domestic market and physical, economic infrastructure (Tandon *et al.,* 2017).

Food accessibility: This is defined as "when individuals have adequate assets or incomes to produce, purchase, or barter to obtain levels of appropriate foods needed to maintain consumption of an adequate diet/nutrition level" (USAID, 1992; Tandon *et al.,* 2017; FAO *et al.,* 2017). This definition means that a household can either produce, buy or exchange resources to obtain food. The assets portfolio or endowment determine the ability of households to produce, buy or exchange resources to obtain food.

Food utilization refers to "the actual food that is consumed by individuals; how it is stored, prepared, and consumed; and what nutritional benefits the individual derives from consumption" (Woller *et al.,* 2013:4). Food utilization is categorized into two dimensions: socio-economic and biological dimension (USAID, 1992; King, 2018). The socio-economic dimension deals with the type of food that is consumed and how food is allocated within the household which is determined by the intra-household dynamics and social customs. The biological dimension is concern with how the human body transforms food into nutrients needed for daily activities or storing energy for future use by the body. Food utilization requires that household's members eat a healthy diet, have a healthy body and live in a healthy physical environment that includes having access to a safe source of drinking water and maintaining good sanitary conditions. It also requires a practical knowledge of proper health care, food storage, food preparation and feeding practices (King, 2018).

Food stability: This is the fourth dimension of food security which cut across the other three dimensions because it involves the time-frame or temporal dimension in the definition that infers to "at all time" (Smith *et al.,* 2017). Hence, food stability is defined as the "ability to access and utilize appropriate levels of nutritious foods over time" (Woller *et al.,* 2013:5; USAID, 1992). Chronic and temporary food security and two important concepts that fall in to this dimension. In chronic food, security households are unable to meet foods needs for an extended period while in transitory food security households only have short-term food deficit. Transitory food security is divided into two groups: cyclical or seasonal food insecurity (happens on a predictable basis, e.g. lean season) and temporary food insecurity (occurs in limited time due to unforeseen circumstance). Both cyclical and temporary food insecurity can interact to cause individuals in households to be vulnerable to food insecurity. For instance, regular session of transitory food insecurity can cause households to sell off or disposed their productive assets and hence shift them into the state of being chronic food insecure (Tandon *et al.,* 2017).

2.1.12. Household Vulnerability to Food Insecurity

FAO (2009) has shown that access to adequate and sufficient food in many countries is unstable. Many households frequently move in and out of a state of food security, suggesting that the notion of food insecurity is best approached in a dynamic sense. Therefore, a framework for analyzing food security must capture its temporal dynamics. Vulnerability analysis offers a solution to this problem by providing a quantitative estimate of the probability that a given household will lose access to sufficient food in the near future (Babatunde *et al.,* 2008).

In the broad academic literature, vulnerability is a term with a variety of discipline specific implications. The disaster management literature generally associates vulnerability with natural hazards (Alwang *et al.* 2001), while both human geography and human ecology relate vulnerability to environmental change (Adger, 2006). Food insecurity and poverty literature, as well as social risk management literature, define vulnerability in terms of future negative effects on welfare (Mansuri and Healy 2001; Dercon 2001; Holzmann and Jørgensen 2000; World Bank 2000). Others define vulnerability in terms of the level of risk and capacity to recover and respond to it. Thus, not only does vulnerability imply a measure of risk associated with physical, social, and economic aspects, it also describes the ability to cope with different risks and shocks (Chambers 1989; Proag 2014). This study shares the definition given by Devereux (2006), vulnerability to food insecurity describes a situation of 'being at risk to become food insecure' Accordingly, there are two components of vulnerability: the external side referring to the structural elements that determine sensitivity and risk to exposure (Chambers 1989; Moser 1998; McCarthy et al. 2001), while the internal side concerns the ability of households to respond and cope with stressors and the actions required to overcome them (Chambers 1989; Bohle 2001; Hart 2009).

The main advantages of the vulnerability approach are twofold. First, it is explicitly dynamic and forward-looking as it considers both current outcomes and future incidences of food insecurity. Second, the analysis uses a stochastic framework and can therefore fully consider the uncertainties associated with future food insecurity, such as the role of external shocks and the strategies that households, communities or public institutions can adopt in order to reduce the likelihood of negative outcomes (Scaramozzino, 2006).

2.1.13. Impact Defined

The concept of impact encompasses the changes that people experience. These changes could involve alterations in knowledge, skills, behaviors, health, or living conditions for children, adults, families, or communities. These changes can have varying impacts on different groups of people over time, resulting from a development intervention, whether intentional or unintentional and can be either anticipated or unexpected. These effects can be economic, sociocultural, institutional, environmental, technological, or other types (UNDP, 2021). The European Commission (2021) provides an additional definition, stating that the term "impact" refers to all changes anticipated as a result of the implementation and application of a particular policy option or intervention. Such impacts may occur over different timescales, affect different actors, and be relevant at different scales (local, regional, and national). In an evaluation context, impact refers to the changes associated with a particular intervention that occurs over the long term.

What is interesting about these definitions is that the term 'impact' embodies many concepts that can be understood and measured in different ways, depending on the context, purpose, and perspective of the analysis. Impact can be seen as the ultimate goal or outcome of any intervention, whether a policy, a program, a project, or an action. Impact can be positive or negative, intended or unintended, direct or indirect, short-term or long-term, and affect different levels and actors of society. Various factors, such as the design, implementation, monitoring, and evaluation of the intervention, the external environment, and the stakeholders involved, can also influence the impact (Gertler *et al.,* 2016). Therefore, impact assessment and evaluation are important tools to identify, assess, and communicate any intervention's impact and inform decision-making and learning processes.

2.2. Causes of Climate Change

Several attempts have been made globally to identify the causes of climate change and its widespread effects on the environment and human well-being. This kind of literature commonly reveals that climate change, which can have devastating consequences, results from some natural processes and many human activities (anthropogenic activities).

Climate change can arise from natural events like shifts in the sun's energy or earth's orbital cycle (natural climate forcing), as well as from human activities such as emitting greenhouse gases, sulfate aerosols, and black carbon into the atmosphere or altering land-use patterns (CCIR, 2005). As Nwankwoala (2015) explains, certain natural factors contribute to climate change and are known as 'climate forcing' or 'forcing mechanisms.' These natural processes, while significant, are often exacerbated by human activities, leading to the current climate crisis. The occurrence of greenhouse gases in the air is a natural element of the climate system and benefits the earth as a habitable planet. Without heat-trapping greenhouse gases (GHGs), the earth would have been a lifeless and frozen planet instead of its present rich, diverse biosphere (Mohanty and Mohanty B., 2009; Nwankwoala, 2015). A volcanic eruption is also another natural process that emits many gases, and one of the most important of these gases is sulfur dioxide (SO2), which forms a sulfur aerosol (SO4) in the atmosphere (Mohanty and Mohanty B., 2009).

In a study by Zilberman *et al.* (2004), it is underscored that the main contributors to global warming and other climate changes are the greenhouse gases that result from human activities. The Fourth Assessment Report of IPCC (2007), the increasing levels of greenhouse gases in the atmosphere, the favorable radiative forcing, the observed warming, and our understanding of the climate system all support the assertion that human activities have an unavoidable impact on the climate system. According to the IPCC (2014) synthesis report, it has been found that human activities, including our own, have been the main drivers of climate change since the mid-20th century. This report also revealed that anthropogenic greenhouse gas emissions have increased since the pre-industrial era because of improvements in economic and population growth rates. This phenomenon has led to increased atmospheric carbon dioxide, methane, and nitrous oxide concentrations.

2.3. Climate Change and Agriculture

Many studies have been conducted to explore the link between climate change and agriculture (for example, Cumhur and Malcolm, 2008; Anita *et al.,* 2010; Dinar and Mendelsohn, 2011; Devendra, 2012; Parvatha, 2014; Yohannes, 2016; Lipper *et al.,* 2018). These studies frequently contend that both the agriculture sector and climate change have an impact on one another. Climate change has a profound impact on humans, the environment, and agriculture. Oladipo (2010) mentioned that climate change has a significant impact on agricultural production, affecting both the quantity of products and the location and area of production. It suggests that the effects of climate change on agriculture will have a significant impact on humanity's future food security. In the same vein, Devendra (2012) and Cumhur and Malcolm (2008) emphasize that climate change is a complex problem involving varied interactions between the environment, natural resources (land, crops, animals, and water), and people. These interactions are likely to change the ecological and agricultural landscapes and, therefore, influence agricultural production.

Herrero *et al.* (2010) highlighted that climate change directly and indirectly impacts the agricultural sector by affecting crop productivity and production. This subsequently leads to economic shocks and fluctuations in prices, which in turn influence food demand, calorie availability, and overall human well-being. David *et al.* (2018) summarize four avenues through which climate change will affect agriculture. These are 1) the global rise in temperatures prompting a shift in climate patterns towards the poles, displacing regions closer to the equator; 2) the escalation of sea levels; 3) alterations in snowmelt patterns and irrigation water availability; and 4) a heightened likelihood of extreme weather events.

In their analysis of a report from the International Food Policy Research Institute (IFPRI), Gerald *et al.* (2009) highlight the various ways in which climate change can affect agriculture and human well-being. They discuss the biological effects on crop yields, the subsequent impacts on factors such as prices, production, and consumption, and the broader effects on per capita calorie consumption and child malnutrition. Additionally, they emphasize how the biophysical changes induced by climate change in agriculture can lead to shifts in production and prices, prompting farmers and other market participants to adjust their strategies in terms of crop mix, input use, production methods, food demand, consumption patterns, and trade. A paper produced by the World Bank (2008) also concluded that climate change affects agriculture through; iii) changes in average temperatures, rainfall, and climate extremes with an important impact on soil erosion (i.e., floods, droughts, etc.). ii) changes in pests and diseases; iii) changes in atmospheric carbon dioxide; iv) changes in the nutritional quality of some foods; v) changes in the growing season; and vi) changes in sea level. While the effects of climate change on agriculture will differ across the world, their impact and consequences tend to be more severe for countries with higher initial temperatures, areas with already degraded lands, and the scarcity of capital for adaptation measures (Parry *et al.,* 2004; Keane, 2009).

In their study, Ruth *et al.* (2011) identified six key areas related to climate change drivers impacting agriculture. These areas encompass a range of factors, including temperature alterations affecting crop growth and livestock performance, changes in precipitation impacting water availability and pest populations, variations in atmospheric CO_2 levels influencing plant and weed growth rates, extreme events such as natural disasters and their impact on production conditions, and sea-level rise affecting ports, transport, and farmland. Additionally, efforts to reduce greenhouse gas emissions may lead to changes in production processes, input costs, and alternative energy opportunities.

Although there is a shortage of literature that deals with climate change impacts on the livestock sector, the existence of a few studies suggests that climate change can affect livestock both directly and indirectly. Direct effects impinge on animal growth, animal products, and reproduction. Indirect effects influence the quantity and quality of feedstuffs such as pasture, forage, and grain, as well as the severity and distribution of livestock diseases and parasites (Seo and Mendelsohn, 2006; Jane, 2008).

On the other hand, agriculture is sensitive to climate change and is one of the major drivers of climate change through persistent anthropogenic forcing. Particularly, the current agricultural activities practiced by developing countries are a significant source of GHGs that aggravate climate disruption (Reddy, 2015). While most GHG emissions can be traced to fossil fuel use for energy, such as burning coal and other fossil fuels for electricity and gasoline combustion in cars, agriculture also plays a contributing role. Agriculture has always contributed some direct emissions, such as methane from animals and carbon dioxide from soils, for example. However, changes in how animals are fed and raised and how much land is cultivated have resulted in increased quantities of these gases being emitted. A relatively new greenhouse gas threat is nitrous oxide, which occurs naturally but has increased markedly because of the growing use of synthetic fertilizers (World Bank, 2008). In the same vein, Yohannes (2016) asserts that changes in natural vegetation and traditional land use, including deforestation for agricultural expansion and fuelwood, are indirect emissions that come from agricultural activities. Likewise, Busari *et al.* (2015) holds the view that intensive tillage is one of the traditional land-use practices that involves continuously disturbing the land and increasing CO_2 emissions by causing the decomposition of soil organic matter, and soil erosion.

However, the existence of diversity between developing countries' agricultural practices and their counterparts' marks variation in the agricultural sector's contribution to climate change. The agricultural practices in developing countries exhibit inefficiency due to limited capital accumulation and worker productivity, the presence of a significant number of cattle, inadequate management of manure, improper utilization of agrochemicals, and mismanagement of land compounds. Consequently, these practices result in the emission of a substantial amount of greenhouse gases (Yohannes, 2016). Smith *et al.* (2007) maintain that three-quarters of agricultural GHG emissions occur in developing countries, and this share may rise above 80% by 2050. Likewise, the FAO (2014) report also showed a 14 percent increase in GHG emissions from 2001–2011 in developing countries due to an expansion of total agricultural outputs. IPCC

(2014) also concludes that total GHG emissions from the agricultural sector are projected to increase over time as the global population and the demand for food continues to grow.

Globally, direct emissions from agriculture are thought to account for between 30 and 40 percent of anthropogenic greenhouse gas emissions (Thornton and Lipper, 2014). Accordingly, the FAO (2009) also disclosed that global deforestation, primarily associated with the growth of agricultural areas, is projected to account for 17.4% of greenhouse gas emissions. The sector's climate impact rises considerably if these land-use changes are added to agriculture's GHG toll. Based on the findings of David and Lal (2013), the agricultural sector is responsible for generating emissions through two primary pathways. Firstly, direct emissions arise from fertilized agricultural soils and livestock manure. Secondly, indirect emissions stem from alterations in natural vegetation and traditional land use practices, such as deforestation and soil degradation. According to the World Bank's World Development Report (2008), it is highlighted that agriculture is responsible for half of the global emissions of two highly potent non-CO_2 greenhouse gases, namely nitrous oxide (N_2O) and methane (CH_4). Non-carbon greenhouse gases (GHGs) possess strong greenhouse effects and exhibit longer lifespans than carbon dioxide (CO_2).

2.4. Environmental Conventions on Climate Change and Agriculture

The first World Climate Conference in 1979, a significant milestone in the history of climate change discussions, marked the emergence of a comprehensive dialogue on this global issue. However, it initially overlooked the crucial aspect of agriculture. Subsequently, various environmental conventions and agreement documents were developed by different organizations, recognizing the vital linkage between climate change and agriculture. For instance, UNFCCC (2009) article 4 (c) emphasizes the need for all parties to promote and cooperate in the development, application, and diffusion of technologies, practices, and processes that control, reduce, or prevent anthropogenic emissions of GHG in all relevant sectors, including agriculture. Similarly, the Paris Agreement Article 4 (e) of UNFCCC (2015) underscores the importance of collaboration in preparing for adaptation to the impacts of climate change, developing and elaborating appropriate and integrated plans for coastal zone management, water resources, and agriculture, and the protection and rehabilitation of areas, particularly in Africa, affected by drought and desertification, as well as floods.

The Kyoto Protocol, a significant agreement, openly addresses the linkage between climate change and agriculture. Article 2 of this protocol not only acknowledges the issue but also promotes sustainable forms of agriculture in light of climate change considerations. Article 3.4 of the Kyoto Protocol further highlights the efficiency of organic agriculture in achieving the carbon sink (UNFCCC, 1997). Moreover, article 10 of this protocol outlines measures to mitigate climate change and facilitate adequate adaptation across various sectors, including agriculture (FAO, 2008). Similarly, the Bali roadmap (IPCC, 2007) emphasizes the need for actions aimed at safeguarding food security and rural livelihoods under climate change, focusing on interactions between adaptation and mitigation strategies in the agricultural and forestry sectors to address climate, environmental, social and economic concerns.

The Copenhagen Accord (2009), another crucial agreement, acknowledges the serious impact of climate change on agriculture and the role of agriculture in mitigating and adapting to climate change (Paul *et al.,* 2009). However, it has not been without its share of criticisms. Some international organizations, such as FAO (2010), have pointed out that while it was a step forward, no specific decisions were made in Copenhagen regarding climate change in the agriculture sector. Similarly, the Cancun Agreement (2010) also recognizes agriculture as a driver of deforestation and thus can be considered under adaptation actions. In line with the Cancun Agreements, the least developed countries articulated national adaptation programs of action (NAPAs) (UNFCCC, 2010).

In conclusion, environmental conventions and agreements have increasingly recognized the vital linkage between climate change and agriculture. The UNFCCC, the Paris Agreement, the Kyoto Protocol, the Bali roadmap, the Copenhagen Accord, and the Cancun Agreement all highlight the importance of agriculture in both mitigating and adapting to climate change. While progress has been made in acknowledging the role of agriculture in climate change discussions, it is crucial to reiterate the need for specific decisions and actions to be taken to address climate change in the agricultural sector. National adaptation programs of action have been developed by least developed countries in line with the agreements, emphasizing the need for collaboration and integrated plans to address the impacts of climate change on agriculture.

2.5. Addressing Climate Change and Environmental Sustainability in Ethiopia

Ethiopia is heavily impacted by climate change due to its significant dependence on natural resources sensitive to climate conditions. Non-climatic drivers such as inappropriate land use and land degradation, population pressure, subsistence farming, low technological innovation and application, and poverty exacerbate the agriculture sector's vulnerability to the impacts of climate change (Nathnael and Hanna, 2017). Additionally, the country faces challenges in securing the necessary financial resources and infrastructure for adapting to these changes and also has limitations in building capacity for adaptation efforts (McSweeney *et al.,* 2010). Addressing these challenges requires policy interventions, and the Ethiopian government has recently taken steps to tackle these pressing adaptation issues.

Ethiopia's climate policies are grounded in various strategic documents and institutional frameworks established at the national level, with specific details tailored to each sector. Ethiopia has previously passed climate-related energy policy in 1994, long before the issue was on the world agenda. Ethiopia’s energy policy is centered on expanding the availability of reliable and affordable energy supplies to support national development goals. The policy sought to improve access to modern energy services, reduce dependency on biomass, and improve the efficiency and sustainability of the energy industry. Recognizing the country's significant renewable energy resources, notably hydropower, the strategy stressed their development to fulfill rising energy demands and promote economic progress (Bekele, 2008). The other most relevant policy addressing climate change is environmental policy, which strongly stresses the importance of observation, evaluation, planning, and implementation at all levels. This policy displays the country's political and technical understanding of the challenges posed by climate change (Sintayehu *et al.,* 2017).

With a strong commitment to addressing climate change, Ethiopia has signed important international accords ahead of time and is putting comprehensive mitigation and adaptation plans into action. The nation signed the Kyoto Protocol and the United Nations Framework Convention on Climate Change (UNFCCC), submitting its first national reports to the UNFCCC in 2001 (Dawson and Spannagle, 2015). The Climate Resilient Green Economy (CRGE) initiative, introduced in 2011, aims to achieve a climate-resilient and middle-income green economy by 2025. It indicates Ethiopia's commitment to deviating from conventional economic development approaches by establishing a green economy in which economic development goals are realized in a sustainable manner (MoPD, 2023). The strategy highlights four pillars of development in the green economic action plan:

a) Improve crop and livestock production practices for higher food security and farmer income while reducing emissions.
b) Protect and reestablish forests for their economic and ecosystem services, including as carbon stocks.
c) Expand electricity generation from renewable energy sources for domestic and regional markets.
d) Leapfrog to modern and energy-efficient technologies in transport, industrial sectors, and buildings.

Moreover, Ethiopia's National Adaptation Plan (NAP-ETH) launched in 2019 aims to reduce climate change's impact on key economic sectors like agriculture, forestry, health, transportation, energy (power), industry, water, and urban areas by building adaptive capacity and resilience (MEFCC, 2019). As part of the Paris Agreement, Ethiopia developed a long-term low emissions development strategy (LT-LEDS) to provide a roadmap for long-term decarbonization. This strategy is built on climate resilience and the green economy strategy and recently, Ethiopia was among the first Least Developed Countries (LDCs) to submit a Nationally Determined Contributions (NDCs) report to the United Nations Framework Convention on Climate Change (MoPD, 2023). Furthermore, the Ten-Year Development Plan, a Pathway to Prosperity 2021-2030, clearly affects all sectors where the LT-LEDS sets emission reduction targets. For example, the plan aims against land degradation, reduce pollution, maintain forests, and promote green urban growth. Similarly, increasing economic productivity aims to increase governmental flexibility, making GHG emission reductions more affordable (MoPD, 2023).

These initiatives are a component of Ethiopia's larger plan to strengthen food security, encourage sustainable natural resource management, and increase agricultural resilience. Ethiopia hopes to lessen vulnerability and create a more resilient agricultural sector by incorporating climate-smart farming practices and enhancing adaptive skills.

2.6. Theoretical Frameworks

This study used the theoretical structure of a random utility to conceptualize climate change adaptation strategies. A random utility model labels a decision in which an individual i has a set of alternative adaptation strategies j from which to choose. The model is framed on the principle that an individual derives utility by choosing some alternatives (Komba and Muchapondwa, 2015; Solomon *et al.,* 2016; Waibel *et al*., 2018). Therefore, a representative farm household will adopt an adaptation strategy only if the expected utility or net benefit from adaptation significantly exceeds that of not adopting it. However, the utility derived from taking on adaptation strategies is not directly observed but through the farmers' choice. Let A^* represent the difference between the utility or benefit of adapting to climate change (U_A) and the utility or net benefit of not adapting $(to\ the\ U_N)$. The typical formulation of the linear random utility model is given as:

$$U_A = \alpha_A{}'Z_i + \varepsilon_A \quad (1)$$

$$U_N = \alpha_N{}'Z_i + \varepsilon_N$$

Where Z_i is a vector of relevant explanatory variables affecting perceived utilities of adaptation, $\alpha_A{}'$ and $\alpha_N{}'$ are the vectors of the parameter estimates for choosing adaptation strategy and not adapting, respectively. Also, ε_A and ε_N are error terms assumed to be independent and identically distributed. However, assumptions about the correlation of error terms of the adaptation equations, i.e., whether correlated or not, decide the type of qualitative choice model to use in the analysis. Thus, a household i will decide to adapt to climate change and variability if

$$A^* = E(U_{iA}) - E(U_{iN}) > 0 \quad (2)$$

Where $E(U_{iA})$ and $E(U_{iN})$ are the expected utility of implementing strategy and not adapting, respectively.

2.7. Analytical Framework

As mentioned in the preceding discussions, smallholder farmers are confronted with a broad and increasing range of gradual climate change (mainly temperature and precipitation) and extreme weather events (mainly droughts and floods). Accordingly, farmers need to adopt specific adaptation strategies to deal with various production constraints and climate risks. Inherently, farmers are more likely to adopt combinations of different adaptation strategies than relying on a single strategy (Piya *et al.,* 2013; Wondimagegn and Lemma, 2016; Ojo and Baiyegunhi, 2019). However, the decision to adopt or not adopt these adaptation strategies may not be random and may be based on individual self-selection (Di Falco, 2014). It is likely that unobservable characteristics of farmers and their farms, such as managerial abilities and motivation, impact adoption decisions and welfare outcomes (Solomon *et al.,* 2012; Hailemariam *et al.,* 2017). Thus, when estimating the welfare impacts of adaptations to climate change and variability on smallholder farmers, the observable and unobservable characteristics of the adopters and non-adopters are imperative.

2.7.1. Determinants of the Choice of Adaptation Strategy by Smallholder Farmers

Several econometric models currently exist to determine the determinants of farmers' adaptation practices to climate change and variability. The most widely used models are the Heckman sample selection probit model (Temesgen *et al.,* 2011; Gutu *et al.,* 2012; Solomon *et al.,* 2016; Paulos and Belay, 2018; Waibel *et al.,* 2018). However, because it lumps all adaptation practices into a single category, this method is invalid for analyzing various adaptation practices, each affected differently by various factors (Piya *et al.,* 2013). Another approach would be to model each adaptation practice individually, i.e., using a univariate technique such as probit or logit analysis for discrete dependent variables (Oyekale and Oladele, 2012; Sahu and Mishra, 2013; Uddin *et al.,* 2014; Franklin *et al.,* 2014; Menike and Keeragala, 2016; Keneilwe and Phatsimo, 2018; Hurgesa *et al.,* 2020). A limitation of univariate models is ignoring correlations among unobserved disturbances in adaptation practices. Thus, they fail to account for the relationships between different choices (Golob and Regan, 2002), which may be complementary or competing.

Another viable approach for determining the key factors that impact the probability of employing various adaptation strategies in response to climate change and variability is through applying of a multinomial discrete choice model (Etwire *et al.,* 2013; Yibekal *et al.,* 2013; Alem *et al.,* 2016; Solomon *et al.,* 2016; Abayneh and Belay, 2017; Amogne *et al.,* 2017; Makate *et al.,* 2019). One significant limitation of using this model is the necessity of adhering to the independence of irrelevant alternatives (IIA) property. This property posits that the likelihood ratio between selecting two alternatives remains unaffected by the characteristics of any additional alternatives within the choices (Hausman and McFadden, 1984). The plausibility of this assumption is called into question because a single household can adopt multiple strategies concurrently (Piya *et al.,* 2013).

However, some other studies (Kurukulasuriya and Mendelsohn, 2008; Alem *et al.,* 2016) have attempted to identify the possible combinations of adaptation strategies and employ the multinomial logit model for adaptation strategies to climate variability and change. A challenge with using combinations as choice variables is that interpreting the simultaneous influence of explanatory variables on the original separate adaptation measures in multinomial replications is difficult (Nhemachena and Hassan, 2007; Piya *et al.,* 2013). Similarly, Young *et al.* (2009) assert that multinomial logit is a poor approximation to the actual underlying outcome probabilities relative to the multivariate probit model. Thus, this study adopts a multivariate probit (MVP) econometric technique to overcome the shortcomings in Heckman, univariate, and multinomial discrete choice techniques. MVP is an econometric model that can model the relationship between a set of explanatory variables and different adaptation strategies. This model also takes into account the correlation between unobserved factors (error terms) that may be positively or negatively correlated due to the presence of complementarities and substitutability between different adaptation strategies (Belderbos *et al.* in 2004 and elaborated upon by Lin *et al.* in 2005).

2.7.2. Impacts of Adaptation Practices on Smallholder Welfare

Various econometric methods have been developed and introduced to measure the impact of climate change adaptation practices on farmer's welfare. The most commonly used method is the Propensity Score Matching (PSM) model to calculate the average treatment effect on the treated (e.g., Ali and Erenstein, 2016; Paulos and Belay, 2018; Ahmad and Afzal, 2020). Based on observed characteristics, the PSM method matches individuals who participate in a treatment program (adapters) with those who do not (non-adapters). This match is done using a model of the probability of participating in the treatment, or propensity score. Adapters are then matched with non-adapters who have similar propensity scores. Finally, the average treatment effect of the program is calculated by comparing the outcomes of these two groups (Khandker *et al.,* 2009). One problem with PSM is that it needs to look at unobservable factors that affect adaptation. It also thinks that the return (coefficient) to characteristics is the same for adapters and non-adapters, but new empirical research (e.g., Di Falco *et al.,* 2011; Khonje *et al.,* 2015) shows that this is only sometimes the case.

Another commonly used model is the instrumental variable (IV) method (e.g., Solomon *et al.,* 2013; Oduniyi and Tekana, 2019). This model relies on the convenience of instruments, a variable (or instrument) highly correlated with adaptation practices but not with unobserved characteristics affecting outcomes. However, finding a good instrument is a potential concern in the empirical analysis. When the instrument is correlated with unobserved characteristics that affect the outcome (i.e., $cov(Z, \varepsilon) \neq 0$), the program effect estimates will be biased; furthermore, suppose the instrument only weakly correlates with the adaptation practices; in that case, the standard error of the IV estimate is likely to increase because the predicted impact on the outcome will be measured less precisely (Bounthavong *et al.,* 2016).

A reasonable approach to tackle the limitations mentioned above could be the multinomial endogenous switching regression model (MESRM), which is the most commonly used method to analyze the impact of adaptation strategies for climate change and variability (Di Falco, 2014; Hailemariam *et al.,* 2017; Wekesa *et al.,* 2018; Issahaku and Abdulai, 2020). Therefore, this study adopts a multinomial endogenous switching regression model (MESRM) because the study involves a multiple adoption setting where farmers' joint adoption of climate change adaptation strategies leads to different possible combinatorial options. The MESRM has an advantage over other methods, such as PSM and IV, as it enables to estimate the impacts of alternative combinations of practices and individual practices on farmer's welfare while considering self-selection biases due to both observable and unobservable factors (Mansur *et al.,* 2008; Wu and Babcock, 1998). MESRM also provides consistent and efficient selection process estimates and reasonable correction for outcome equations, even when the IIA hypothesis is violated (Bourguignon *et al.,* 2007).

The MESRM, however, needs at least one selection instrument that affects the adaptation decision of farming households but does not affect the outcome variables. However, finding an instrumental variable is tedious and challenging in the empirical analysis (Fissha *et al*., 2019).

2.7.3. Impacts of Adaptation Strategies on Vulnerability to Food Insecurity

This study employs a multinomial endogenous treatment effects (METE) approach to quantify the impact of adopting climate change adaptation strategies on vulnerability to food insecurity.

The multinomial endogenous treatment effects model (Deb and Trivedi, 2006) offers a more comprehensive and flexible approach to estimating binary outcome variables, considering the issues of endogeneity and providing insights into treatment effects across adoption of single, as well as combinations of climate change adaptation strategies. Therefore, the multinomial endogenous treatment effect (METE) model is preferred due to its capacity to incorporate binary outcomes, in contrast to multinomial endogenous switching regression (MESR), which focuses on continuous outcomes (Khonje *et al.,* 2018).

2.7.3.1. Approaches to vulnerability analysis

Vulnerability to food insecurity (VFI) is a complex issue that lacks a unique indicator for measurement, as noted by the FAO (2002) and further elaborated by researchers such as Ligon and Schechter (2004) and Løvendal and Knowles (2005). Consequently, multiple methodologies have emerged to assess VFI, with three principal approaches gaining prominence in the literature.

The first approach conceptualizes vulnerability as expected poverty (VEP). This framework estimates the likelihood that individuals or households will experience a decline in well-being, potentially falling below a defined threshold such as the food poverty line due to various shocks (Pritchett *et al.,* 2000; Chaudhuri *et al.,* 2002; Chaudhuri, 2003; Christiaensen and Subbarao, 2005; Bogale, 2012). Researchers employing this method focus on predicting future trajectories of poverty based on exposure to risks.

The second approach quantifies vulnerability as low expected utility (VEU). This method examines the shift in utility from a certainty equivalent level of consumption a benchmark compared to the household's anticipated utility (Ligon and Schechter, 2003; Hoddinott and Quisumbing, 2003). Proponents of VEU argue that the VEP methodology does not align with the expected utility theory, advocating for this alternative measure to better capture vulnerability dynamics.

Lastly, vulnerability as uninsured exposure to risk (VER) provides a distinct perspective. Unlike the previous approaches, VER evaluates the degree to which specific shocks result in welfare losses due to inadequate risk management strategies. This method serves as an ex-post assessment, focusing on the consequences of shocks rather than attempting to create a comprehensive vulnerability measure (Hoogeveen *et al.,* 2004; Cruces, 2005; Cruces and Wodon, 2007).

In assessing vulnerability to food insecurity (VFI), all the three methodologies; expected poverty (VEP), low expected utility (VEU), and uninsured exposure to risk (VER) depend on the expected mean and variance in household consumption or income. The VEP technique may be utilized with both cross-sectional and panel data, but the VEU and VER frameworks require comprehensive panel datasets for thorough analysis. Given the challenges associated with acquiring suitable panel data, this study focuses on assessing household VFI through the VEP approach, utilizing cross-sectional data to identify the factors influencing vulnerability. However, achieving an accurate estimate of household VFI necessitates a careful examination of the distribution of food consumption, as disparities in consumption patterns can significantly impact vulnerability assessments.

2.8. Empirical Review

This section reviews the empirical literature on factors influencing climate change perception and adaptation practices and how these practices impact farm income, vulnerability to food insecurity, and cost of risk in Ethiopia and elsewhere.

2.8.1. Determinants of Farmer's Adaptation Strategies to Climate Change Impacts

Abraham *et al.* (2017) analyzed smallholder farmers' perceptions of climate change and the factors influencing their adaptation choices in the central Rift Valley of Ethiopia. The analysis indicates that farmers in the study area have perceived long-term weather variability and climate change over the past two decades. The findings obtained from a multinomial logit model indicate that male-headed households with larger family sizes and higher levels of education have a greater capacity to choose effective adaptation options. Additionally, the household head's age positively impacts the decision to practice specific adaptation strategies, such as soil and water conservation and changing crop varieties. In contrast, household head age is negatively related to the probability of the household adapting to climate change through tree planting. Moreover, farm size, income, access to markets, access to climate information and extension, and livestock production are the key factors determining farmers' choice of adaptation practice. Although this study did not specifically recommend any mechanism or kind of adaptation to climate change, it implicitly mentioned that supporting the indigenous approaches of smallholder farmers via institutional and technological instruments is imperative for adaptation and mitigation.

Paulos and Belay's (2018) study used the Heckman sample selection model to examine what makes people in the Dabus Watershed think about and react to climate change. The study focused on two agroclimatic zones: wet lowland and dry lowland. Accordingly, they found that the farmers in the study area perceive climate change and have devised a means to survive by implementing different adaptation strategies. Household size, the gender of the household head, cultivated land size, education, farm experience, non-farm income, income from livestock, climate information, extension advice, farm-home distance, and number of parcels influence farmers' adaptation decisions in wet and dry lowland conditions. However, the direction and significance levels of most explanatory variables differ between the two study areas. One caveat of this study is the approach employed to examine adaptation, which is Heckman's sample selection model, which puts all the adaptation practices into a single category. Thus far, the adaptation practices have been affected differently by various factors.

Abayineh and Belay (2017) conducted a study to investigate the factors affecting the adoption of adaptation options by smallholder farmers in Ethiopia's Muger River sub-basin of the Blue Nile basin in response to climate change and variability. They used a multinomial logit model for their study. The study found that small-scale irrigation as an adaptation to climate change is positively influenced by credit access, social capital, and household head education. Greater distance to the marketplace and the size of farmland has a negative impact on crop management practices. In contrast, access to early warning systems and experience with crop failure have a positive influence. The study indicates that early warning systems, increased distance from the market, and larger cultivated land sizes positively impact soil and water conservation adoption. There are specific problems with using a multinomial choice model in the analysis of adaptations to climate change. A critical requirement in decision-making is the independence of irrelevant alternatives (IIA) property. It implies that the ratio of probabilities of choosing any two alternatives should not be affected by the attributes of any other alternative (Hausman and McFadden, 1984). However, this assumption is not plausible because a single household can adopt multiple strategies (Piya *et al.,* 2013).

A recent study by Hurgesa *et al.* (2020) examined the determinants of adaptation strategies to climate change among smallholder farmers in the Adama district using a binary logistic regression model. The results indicated that planting trees, adjusting planting seasons, using improved crop varieties, practicing watershed management, diversifying crops, and practicing terracing are some of the climate change adaptation activities applied by the smallholder farmers of the study area. The binary logistic regression model showed that the practices of adapting to climate change are strongly affected by the age and gender of household heads, their level of education, the size of their family, their access to agricultural extension services, and their training on adaptation practices. A significant problem with the binary probit or logit model in the context of climate change adaptation strategies is that it needs to account for the possible interrelationships between the various adaptation strategies. At the same time, inherently, farmers are more likely to adopt a mix of strategies than rely on a single strategy (Yu *et al.,* 2008).

Fikeremaryam *et al.* (2016) looked at what factors affect farmers' decisions about adapting to climate change, which causes food shortages, heat stress, and a lack of water and pasture for sheep and goats in southern and central Tigray, Ethiopia. The estimation of the multivariate probit model showed that farmers' choices about adapting to climate change were affected by their income, the number of households in a village, their access to information, and the agroecological settings in which they lived. Furthermore, OLS revealed that the adaptation strategies positively influenced household income. However, certain drawbacks are associated with using OLS to analyze the influence of adaptation strategies on a household's income. Since adopters were not assigned randomly, using OLS would have produced biased and inconsistent estimates (Issahaku and Abdulai, 2020).

2.8.2. Impacts of Adaptations to Climate Change and Variability on Farmer's Welfare

A recent study by Fissha *et al.* (2019) aims to examine the effect of climate change adaptation strategies on farm household's welfare in the Nile basin of Ethiopia. The authors develop an endogenous switching regression model to find out how crop diversification affects the welfare of farm households. They use net farm income and household labor demand as welfare indicators. It was found that climate variables have heterogeneous effects on farm income between adopters and non-adopters of crop diversification. The study also pointed out the win-

win effect of adopting crop diversification, which positively and significantly affects farm income and reduces demand for on-farm labor. The results suggested that adopting crop diversification helps improve the wellbeing of farm households and builds a resilient agricultural system. However, this study is highly aggregated and only made its analysis with a single adaptation strategy, paying no attention to other adaptation practices on-farm net income. Nevertheless, in practice, farmers are more likely to adopt a mix of different adaptation strategies simultaneously to deal with a host of production constraints than to adopt a single strategy. Moreover, various climate change adaptation strategies at the farm level are indispensable to addressing the welfare edges (Hailemariam *et al.,* 2019).

Another recent study by Tsega *et al.* (2019) investigated the impact of adaptation practices such as improved seed, diversification, irrigation, and modifying planting and harvesting times on crop productivity in northwest Ethiopia. An endogenous switching regression model was used in the study to deal with selection biases caused by factors that could be observable or unobservable. The results suggested that farmers who adopted adaptation strategies would have gained lower yields if they had not adopted them, and those who did not adopt a strategy would have gained higher yields than if they had. However, the study lumps all adaptation practices into a single category, while various factors affect different adaptation practices differently. Instead, it provides valuable insight into the effects of single or individual adaptation practices. However, in reality, farmers may decide to undertake combinations of adaptation measures to exploit complementarities or substitutability among alternatives.

Moreover, the study would have been more interesting if it had included risk evaluation for adaptation practices. Assessing the cost of risk allows stakeholders to develop sustainable and resilient long-term adaptation plans. By considering the financial implications associated with different adaptation strategies, communities can make informed decisions that benefit future generations and contribute to a more resilient society. Furthermore, evaluating the cost of risk helps identify cost-effective strategies for reducing vulnerabilities to climate change impacts, ultimately mitigating potential losses and damages in the future.

A study undertaken by Melaku *et al.* (2017) also investigated perception and adaptation to climate change and whether these practices have brought about any improvement in the farm income of different communities in the Afar region. The study employed a fixed-effects quantitative model on the panel data. The results suggested that the main adaptation strategies that significantly influenced household income levels were forage production (hay and straw), access to water sources, livestock diversification, and migration. This study can provide helpful input into policy-making decisions regarding pastoral areas; however, livelihood strategies and adaptation practices pursued by the Afar communities differ from those of Bench Maji. Hence, not considering the contextual and spatial variations of adaptation strategies and their adaptive capacities may result in incorrect conclusions about their effects (Smit and Wandel, 2006).

A study by Paulos and Belay (2018) analyzed the likely impact of adaptation to climate change through climate-smart agricultural practices on farm productivity and production risk management in the Blue Nile Basin of Northwest Ethiopia. Applying the propensity score matching (PSM) technique revealed that households that implemented climate-smart agricultural practices as an adaptation strategy experienced higher production value than non-users due to lower climate-related risks that led to yield variability. However, the propensity score matching (PSM) technique in adaptation strategies for climate change and variability analysis has been criticized because it needs to account for the unobservable characteristics of farmers. If selection bias from unobserved heterogeneity is likely thoughtful, then PSM may provide a biased result (Khandker *et al.,* 2009).

Hailemariam *et al.* (2017) examined the impact of adaptation to climate change through various combinations of climate-smart practices such as agricultural water management, improved crop seeds, and fertilizer on farm net income. The study employed a multinomial endogenous switching regression to model the impact of household and farm characteristics, climatic variables, and combinations of practices on net farm income. The results suggested that net farm income positively responds to agricultural water management, improved crop variety, and fertilizer when these practices are adopted in isolation and combination. However, this effect is more significant when the practices are combined. Although this study can provide helpful input into policy-making decisions in adopting multiple climate-smart practices, it has significant limitations. First, this study was conducted at the sub-regional level in the Nile River basin based on plot household-level data from the farm household survey, which was undertaken for five years. Hence, it is highly aggregated and dated to provide micro-level evidence, while climate change adaptation is a continuous process requiring location-specific responses (Malo *et al.,* 2010).

Therefore, complementing the sub-regional evidence with adaptation measures and impact by the micro-level analysis, such as the Bench Maji zone, is equally essential for generating context-specific practical adaptation strategies that will support the resilience of smallholder farmers.

2.8.3. Impact of Adaptation Strategies on Risk Exposure and the Cost of Risk

Kim *et al.* (2014) used quantile regression to estimate the quantile-based cost of risk for Korean rice farmers, who face uncertainty in their crop yields due to weather and pests. The authors find that irrigation reduces the cost of risk for the farmers, especially at the lower quantiles, where the downside risk is high. They also find that about 90% of the cost of risk comes from the risk exposure in the first quantile of the yield distribution. However, this study is more plausible if it includes other adaptation strategies farmer's practice.

Di Falco and Veronesi (2014) study assessed the impact of climate change adaptation on downside risk exposure for farm households in the Ethiopian Nile Basin. The study uses a moment-based method that uses the third moment of a stochastic production function to measure the uncertainty in the downside yield. Then, they estimated a simultaneous equation model with endogenous switching to account for unobservable factors influencing downside risk exposure and the decision to adapt. The results have shown that farm households that implement climate change adaptation strategies benefit from decreasing the risk of crop failure. Moreover, adaptation would have benefited farm households that previously did not adapt if they adapted. The results also show that adapting to climate change is a successful strategy for managing risk and increasing resilience to climatic conditions. Instead of grouping the various adaptation practices into a single category, the study would have been more interesting if it had differentiated them. It is also based on the data set collected over a decade ago and is highly aggregated. As a result, providing an updated and context-specific impact of climate change adaptation on farm households' downside risk exposure and the cost of risk has little significance.

Issahaku and Abdulai (2020) conducted a study on the impact of joint adoption of climate-smart agricultural practices, such as crop choice and soil and water conservation practices, on mixed-crop farmers in Ghana. The study focuses on how these practices can affect crop revenue and exposure to production risk, measured as crop revenue skewness. A multinomial endogenous switching regression model was used to fix any selection bias from known or unknown heterogeneity. The study found that adopting crop choice and soil and water conservation practices increased crop revenues and decreased production risk. Joint adoption had the most significant impact on crop revenues. While this study provides worthwhile input on evaluating risk exposure for the agricultural sector, it focuses on measures relying on full moments such as variance and skewness. A significant problem with full moment-based risk evaluation is that it is limited to providing a more flexible way to examine the nature and economic implications of downside risk.

Empirical research has primarily focused on farmers' adaptation measures to climate change and variability. Such measures may include adjustments in both behavior and resource technology. Moreover, except for a few studies (Fissha *et al.,* 2019; Di Falco, 2014), most ignore the welfare effects of adaptation measures undertaken by farmers to deal with climate change. Some of them are too aggregated to show how local climate change and variability affect farmers' lives, how they adapt, how farmers think about climate change and variability, the problems they face, and what factors affect their adaptation strategies in a particular place. However, climate change adaptation is a continuous process requiring a location-specific response. Thus, to design specific and compelling adaptation policies, it is vital to estimate the impact of various adaptation practices in line with the factors determining farmer's adaptation decisions to climate change.

2.9. Conceptual Framework of the Study

In response to the long-term challenges posed by climate change and variability, policy intervention in agriculture can be broadly categorized into two primary strategies: mitigation and adaptation. Mitigation focuses on reducing the rate and magnitude of climate change by addressing its human-induced causes, primarily through the reduction of greenhouse gas emissions and the enhancement of carbon absorption. This strategy aims to create a sustainable agricultural system that minimizes environmental degradation while ensuring food security. By implementing effective mitigation measures, agricultural practices can evolve to become more resilient, thereby contributing to a healthier planet and securing livelihoods for vulnerable populations.

Conversely, adaptation strategies are essential for addressing the immediate impacts of climate change and variability, particularly in the agricultural sector, where many impoverished individuals depend on rain-fed agriculture for their livelihoods. As outlined by Maddison (2006), adaptation is a two-step process: first, farmers must recognize the presence and implications of climate change; second, they must decide on and implement specific strategies to mitigate the associated risks. This process is not without its challenges, as farmers often face barriers in accessing resources and information necessary for effective adaptation. Thus, understanding the nuances of farmer decision-making in response to climate variability is critical for developing targeted interventions that enhance resilience.

The choice of adaptation strategies is influenced by a variety of contextual factors, including socio-economic conditions, institutional frameworks, and infrastructural availability. These factors play a pivotal role in shaping farmers' perceptions of climate risks and their subsequent decisions regarding adaptation. For instance, wealthier households may have more access to resources that facilitate adaptation, such as technology or improved agricultural practices, while poorer households may be limited in their options. Additionally, farm characteristics, such as size and type of crops grown, significantly affect how farmers respond to climate-related challenges. Environmental factors, including local climate conditions and soil quality, further complicate the decision-making process, as they can dictate the feasibility and effectiveness of certain adaptation strategies.

The outcomes of the adaptation strategies employed by farmers can vary widely, leading to both positive and negative consequences. When farmers experience beneficial results from their chosen strategies, such as increased farm income or reduced risk exposure, they are likely to reinforce their commitment to these practices over time. This iterative process creates a feedback loop where successful adaptations encourage further investments in resilience-building measures. Conversely, if the attempted adaptations yield detrimental outcomes, farmers may become discouraged and less likely to pursue innovative strategies in the future. These dynamic highlights the importance of continuous support and education for farmers, enabling them to navigate the complexities of climate change effectively.

The conceptual framework illustrated in Figure 1 encapsulates the interplay between climate change, contextual factors, and household adaptation behaviors. It emphasizes the importance of understanding how socio-economic, institutional, and environmental contexts influence farmers' perceptions and choices regarding adaptation strategies. Additionally, the framework underscores the critical role of actors, including farm households and local governments, in shaping adaptation outcomes. By measuring household welfare through indicators such as farm income, risk exposure, and vulnerability to food insecurity, this study aims to shed light on the effectiveness of various adaptation strategies. Ultimately, the findings will contribute to developing more effective agricultural policies that enhance resilience in the face of climate change while promoting sustainable livelihoods for vulnerable populations.

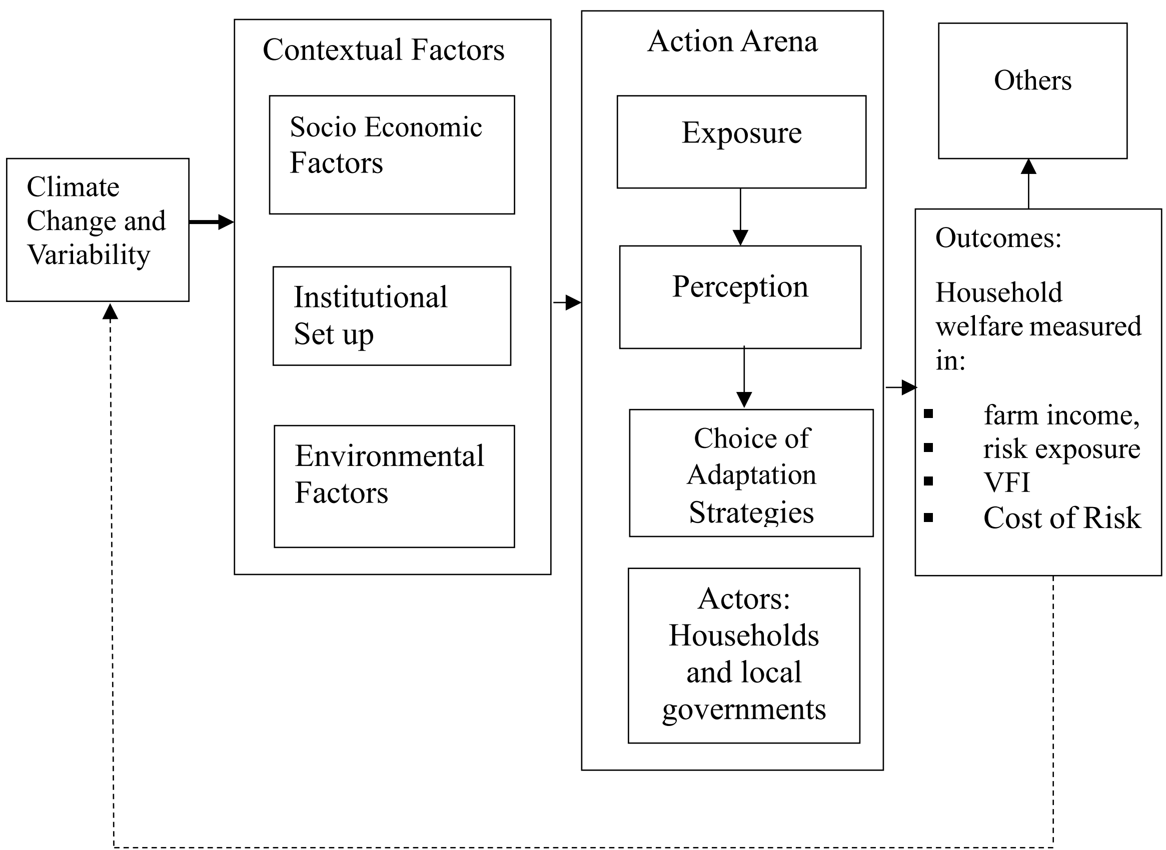

Figure 1. Conceptual framework on climate change adaptation strategies and their impact.
Source: own formulation based on IAD[1] framework.

[1] An institutional framework which identifies the major types of structural variables present to some extent in all institutional arrangements, but whose values differ from one type of institutional arrangement to another (Menard and Shirley, 2005).

3. RESEARCH METHODOLOGY

This chapter gives the details of the methodology used to address the research questions and achieve the objectives of the study. The section gives an overview of the features of the study area, focusing on the physical characteristics, demographic characteristics, and socioeconomic conditions. The chapter also elaborates on the research methodology, including sampling technique and sample size, data collection instruments and techniques, and analysis. Furthermore, this chapter defines the variables used in subsequent chapters and explains their construction and measurement. Additionally, it presents summary statistics of the variables.

3.1. Description of the Study Area

3.1.1. Location and Administrative Division

Bench Maji Zone is one of the zones in Southwest Ethiopia Peoples Regional State (SWEPR) that makes up the southwest part of the country and lies between 5.34–7.53°N latitude and 35.13–36.23°E longitude, covering about 19,326.59 km^2. The zone is located at a distance of 582 km from Addis Ababa. As depicted in Fig. 2, the zone is bounded by the Kafa zone in the north and northeast, the Sheka zone in the northwest, the South Omo zone in the southeast, the Gambela region, and the South Sudan Republic in the southwest and south, respectively. Bench Maji[2] zone consists of ten districts and one town administration, which includes 245 rural and six town kebeles. Mizan Aman is the administrative town of Bench Maji (BMZFEDD, 2017).

3.1.2. Altitude and Climate

The mean temperature of the zone ranges between 15 ºC and 27 ºC, while the average annual rainfall varies from 400mm to 2000mm. Bench Maji Zone has diverse climate zones with different proportional coverage. Based on the traditional agroecology classification, the zone is classified into Dega (5%), Woynadega (45%), and Kola (50%). The zone has a diverse topography, with peak highlands (2%), midlands (53%), and lowlands (45%), which together create diversified agroecological conditions. The wide range of variation in altitude of the zone, which varies from 500m above sea level (m.a.s.) to 3000m above sea level (m.a.s.), governs the temperature range and climatic conditions in the zone (BMZFEDD, 2017).

[2]Currently, the zone is divided into two zones, namely Bench Sheko and West Omo Zone.

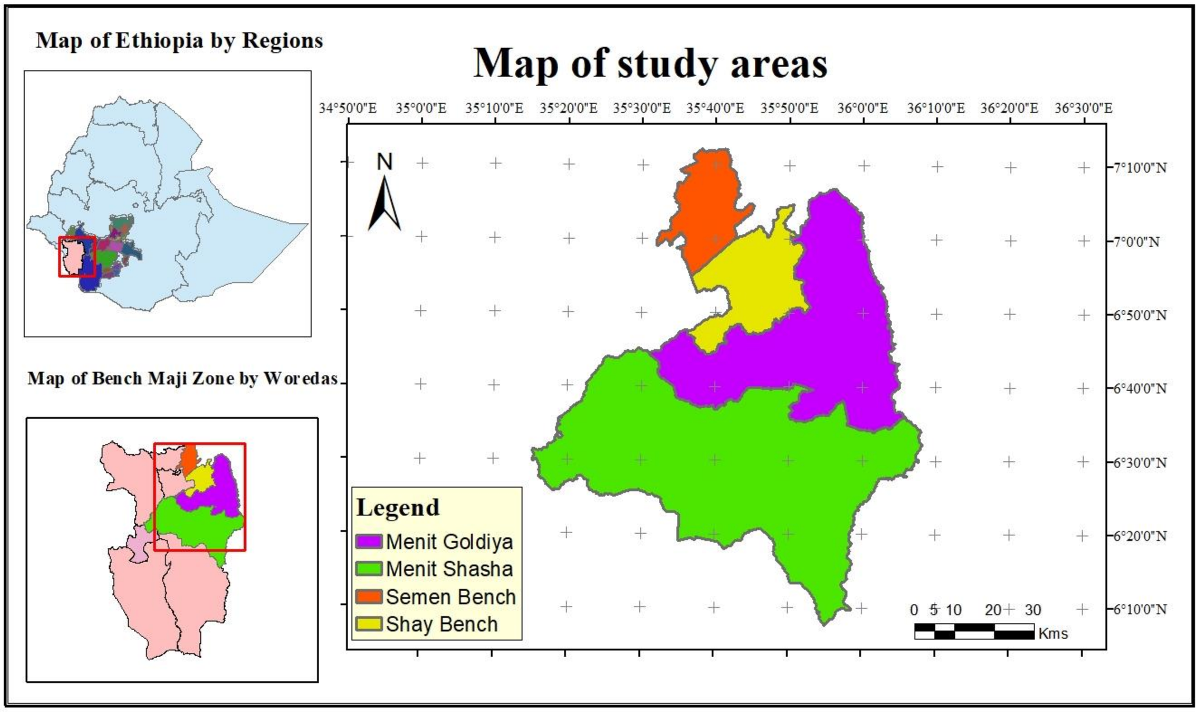

Figure 2. Map of the study areas (2019)

Source: BMZFED

3.1.3. Demography

The population of the Bench Maji zone has been growing over the past few years. According to the CSA (2007) national census, the zone's population was 659,046. Based on this, with an average annual growth rate of 2.9%, the zone's population size is projected and estimated in 2018 to be 1,066,918, of which about 537,313 (50.36%) are male and the rest, 529,605 (49.64%) are female. There are an estimated 181,587 rural households, of which 69.31% are male-headed and 30.69% are female-headed, highlighting the gender distribution within the zone. The crude population density in the zone is estimated to be 55.2 persons per square kilometer, with an average family size of 4.47 people per household. A considerable disparity exists among its districts, ranging from 3.19 in Surma to 4.94 in Menit Goldiya districts (BMZFEDD, 2018).

3.1.4. Agriculture and Land Use Pattern

Today, like any other part of the country, rain-fed agriculture is the primary sector that dominates the livelihood of the Bench Maji Zone. However, traditional and modern irrigation produces vegetables and fruit crops. Other economic activities of the zone include extensive livestock production, poorly developed support services, and uneven market access. According to Bench

Maji Zone Agricultural Development Department (BMZADD, 2017), the most significant proportion of the study area comprises cultivable land (41.4%), in which, in 2017/18, about 51.92 percent is cultivated and covered with annual and perennial crops, followed by other forms of land (14.55%), grazing lands (11.08%), and forest and shrubs (4.61%). As stated by the zone natural resource and environmental protection office report (BMZFNRD, 2017), the natural forest resource of the zone has been over-exploited and hence accelerated severe deforestation and environmental degradation in the zone. It is closely linked with re-settlement, unplanned land use management, and uncontrolled exploitation of natural resources.

Most people residing in the area are involved in diversified agricultural practices. Agricultural activities encompass both crop cultivation and livestock production. The cultivation of crops predominantly relies on rain, except for limited areas where traditional and small-scale irrigation methods are employed for vegetable cultivation. There are two distinct rainy seasons, namely Kiremt and Belg, which are utilized to cultivate long-cycle crops. According to the Bench Maji Zone Agricultural Development Department (BMZADD, 2017), coffee, spices, and fruit crops are among the essential perennial cash crops in the zone. Among the annual crops, maize, sorghum, root, and tuber cover the bulk of crop production. Land preparation primarily involves the utilization of ox-plowing; however, manual tilling is employed in mountainous regions characterized by steep slopes. In recent times, there has been a significant decline in crop productivity. Consequently, a significant number of individuals engage in seasonal migration to Mizan Aman town as a means of supplementing their means of subsistence.

3.2. Sampling Technique and Methods of Data Collection

3.2.1. Sampling Technique

In this study, a meticulously designed multistage sampling technique, a combination of both probability and non-probability sampling techniques, was employed to draw appropriate districts, kebeles, and households. The first stage involved the purposeful selection of four districts, namely Semen Bench, Shey Bench, Menit Goldiya, and Menit Shasha, from the districts of the Bench Maji Zone. These areas were chosen due to their higher vulnerability to climate-related shocks and, consequently, their greater exposure to climate change-related risks. These climate-related hazards include crop pests, livestock diseases, food production shortfalls, seasonal flooding, and more severe and continual landslides (BMZFNRD, 2018). There are 31, 21, 31, and 27 kebeles in Semen Bench, Shey Bench, Menit Goldiya, and Menit Shasha, respectively.

In the second stage, depending on the distribution of kebeles in each sample district, four kebeles from the Semen Bench district, three kebeles from the Shey Bench district, four kebeles from the Menit Goldiya district, and three kebeles from the Menit Shasha district were randomly selected. There are 7,531, 38,890, 23,895, and 19,700 total households in the Semen Bench, Shey Bench, Menit Goldiya, and Menit Shasha districts, respectively (BMZFEDD, 2018). In the third stage, a representative sample of 426 farmers was selected using a random sampling technique based on the proportionate probability sampling procedure, which relies on the respective number of farm households in Kebeles.

The appropriate sample size for a population-based survey is primarily determined by three factors: the estimated prevalence of the variable of interest, the desired level of confidence, and the acceptable margin of error (IFAD, 2011). Following Kothari (2004) and Anderson *et al.* (2007) to yield a representative sample for the known population, this study used the following formula to estimate the minimum sample size for the study from the study population:

$$n = \frac{Z^2 * p(1-p) * N}{e^2(N-1) + Z^2 * p(1-p)} \quad (3)$$

The sample size computation for the selection of households from each district took into account (i) a 5% margin of error ($e = 0.05$) at 95 % confidence ($Z = 1.96$); (ii) $N = 90{,}016$; (iii) the proportion (p) for the different variables under investigation ($p = 0.88$). Moreover, to be consistent with many previous studies of such type (Solomon *et al.,* 2016; Paulos and Belay, 2018; Phiri, 2011), which factored in a design effect ranging from 1.5 to 2.5, this calculation has also considered a design effect of 2.5 to address the multistage sampling inherent errors. Additionally, a 5% non-response rate (NRR) has been accounted for to accommodate households that may be unavailable, inaccessible, uncooperative, or have any other hindrance preventing survey teams from reaching the selected household. Based on this evidence, the sample size of this study is calculated as follows:

$$n = \frac{[(1.96)^2 * 0.88(1-0.88) * 90{,}016] * 2.5}{0.05^2(90{,}016-1) + (1.96)^2 * 0.88(1-0.88)} = 404.9 \approx 405$$

It is expected to have about a 5% non-response rate; the final sample size is given as follows:

$$\text{Final sample size} = \frac{Numberof\ household\ needed}{1 - NRR}$$

Where NRR is referred to non-response rate. The sample size that would now be necessary is

$$\text{Final sample size} = \frac{405}{1 - 0.05} = 426.31 \approx 426$$

Therefore, 426 sample households was the theoretical minimum sample size required for the study.

Out of the total sample size, 19 farm households were assigned to participate in the pilot survey. Subsequently, they were excluded from the dataset utilized in this study. Furthermore, it should be noted that following the completion of the survey, it was determined that 17 questionnaires exhibited incompleteness, with the absence of pertinent information pertaining to certain target variables. Subsequently, these data points were excluded or omitted from the analysis. Therefore, the sample size of the study comprised 390 households, resulting in an impressive, effective response rate of 96%. Table 1 presents the sample size before and after the survey across kebeles.

Table 1. Distribution of sample farm households by across sampled districts and kebeles

District	Kebele	Household head	Prior sample	Actual sample
Menit Goldiya	Bazum	608	38	34
	Yarxa	204	13	10
	Boru	326	20	17
	Kubut	448	28	24
Menit Shasha	Wujinalemu	328	20	17
	Yirni	361	22	20
	Baro	407	25	24
Shey Bench	Maz	734	46	44
	Maha	868	54	52
	Biack	764	48	45
Semen Bench	Dacken	644	40	38
	Oka	362	23	21
	Temenjyazh	474	29	27
	Goal	322	20	17
Total		**6850**	**426**	**390**

Source: Kebele Administration Office (Personal Communication)

3.2.2. Data Types, Sources and Methods of Data Collection

The study used quantitative and qualitative data to capture information on the farmer's perception and adaptation to climate change and variability and its impact on farmers' welfare. Hence, pertinent data was derived from primary and secondary sources. Two types of data-gathering tools were used in the study. One is a structured questionnaire for gathering data from sampled rural households. The other tool is an in-depth interview, which was conducted with a total of 14 selected individuals (one from each kebele) who were considered knowledgeable about the issues of climate change and variability and its impacts on the agriculture production system and adaptation practices of the farmers in the study districts.

For the quantitative investigation, the questionnaire was developed and pilot-tested to ensure validity and accuracy. It was reviewed before being used for the final information-gathering process. Moreover, the enumerators received field training about the study objectives and farm household survey. The instruments focused on significant areas such as past climate-related shock experiences, socioeconomic characteristics, crop and domestic livestock management, land tenure, farm inputs and outputs, access to institutional services, knowledge of climate change and variability, and current adaptation measures being undertaken.

Secondary data were also reviewed as a complement to identify and evaluate existing gaps. The secondary dataset contains information on the location, administrative division, population, economy, farming, and land use patterns of the study area. This data was collected from the respective offices of the Bench Maji Zone. Some secondary data, such as time series temperature and rainfall data, was extracted from the Aman branch office of the National Metrological Service Agency of Ethiopia (NMSAE). Moreover, the Mann-Kendall non-parametric trend test detected significant trends among these climatic variables (rainfall and temperature).

3.3. Methods of Data Analysis

The study used both quantitative and qualitative methods to analyze the data. However, it primarily relied on a quantitative approach, with some qualitative data included. Descriptive statistics and an econometric model were both used in the analysis of the quantitative data. These methods were used to acquire a thorough grasp of the data and derive valuable insights. The upcoming section will delve deeper into these methodologies and provide a detailed explanation of how they were utilized in the analysis.

3.3.1. Descriptive Statistics

The sampled farmers' demographic and socioeconomic data were analyzed using descriptive tools such as mean, percentage, standard deviation, and frequency distribution. Additionally, their perceptions of climate change, its impacts on agriculture, and the adaptation practices they had been implementing on their farmland were studied. The most frequent climate-related shocks experienced by them were also examined. Furthermore, t-test and $\chi 2$-test statistics were used to compare those who do not adapt for some explanatory variables. Moreover, the five-point Likert scale elicited information on the respondent's perceptions of climate change and climate-induced hazards. Together, the Likert scale and the descriptive analysis of the household survey data addressed research question number one.

3.3.2. Econometric Models

This study uses four different types of econometric models to look at the data. These are the multivariate probit model, the multinomial endogenous switching regression model (MESRM), the multinomial endogenous treatment effect model (METE), and the quantile moment-based risk analysis. The multivariate probit model is used to identify and analyze the determinants of adaptation strategies to climate change among smallholder farmers. The MESRM is used to evaluate the impact of implementing individual and combined strategies for adapting to climate change on farm income and downside risk. The METE model is employed for the purpose of estimating the effects of climate change adaptation measures on the vulnerability of households to food insecurity. Finally, a quantile moment-based risk analysis approach is used to assess the cost implications associated with adopting single and combined climate change adaptation practices, specifically the impact of the adoption of climate change adaptation strategies on the cost of risk.

3.3.2.1. Modeling determinants of adaptation strategies to climate change

As stated in the analytical framework section, the study relies on the multivariate probit model to examine the factors influencing the adaptation choices made by smallholder farmers in the study area. The MVP estimation technique is a binary response regression model that assesses the effects of a range of covariates on each adaptation strategy while also considering potential correlations between unobserved disturbances (error terms) (Lin *et al.,* 2005; Young *et al.,* 2009). Correlations may arise due to complementarities (positive correlation) and substitutability (negative correlation) between different adaptation strategies (Belderbos *et al.*, 2004). This correlation implies that the decision to adopt a particular adaptation strategy may depend on the choice of another strategy.

In line with the research conducted by Hailemariam *et al.* (2019) and Arun and Jun-Ho (2019), this study developed a multivariate probit model that included four sets of binary choice equations. These equations focused on various aspects such as crop diversification (CD), improved crop varieties (IV), soil and water conservation (SWC), and livelihood diversification (LLD). Let ${M_{ipj}}^*$ be the latent variable that captures the net benefit that the i^{th} household drives from implementing $the\ j^{th}$ $(j = CD, IV, SWC, LLD)$ strategy on its farm plot p $(p = 1, \dots, P)$. Thus, the latent variable is specified as:

$$
{M_{ipj}}^* = \varphi_j {X'}_{ipj} + \varepsilon_{ipj,} \qquad j = CD, IV,\ SWC, LLD \tag{4}
$$

Where ${X'}_{ipj}$ represents observed household and plot-specific characteristics and institutional variables used in the model, φ is a vector of coefficients, and ε_{ipj} is a random error term assumed to be distributed as a multivariate normal distribution. In this study, the unobserved preferences associated with the j^{th} choice of adaptation strategies in Equation (4) transform into the observed binary outcome equation as follows:

$$
M_{ipj} = \begin{cases} 1 & if\ \varphi_j {X'}_{ipj} + \varepsilon_{ipj} > 0 \\ 0 & if\ \varphi_j {X'}_{ipj} + \varepsilon_{ipj} \leq 0 \end{cases} \qquad j = CD, SWC, LLD \tag{5}
$$

M_{ipj} denotes a vector of observed binary responses, taking values 1 for farmers practicing adaptation strategies and 0 for those not. Since adaptation practices are often adopted simultaneously, the error terms conform to a multivariate normal distribution with zero means, unitary variance, and an $n \times n$ contemporaneous correlation matrix (Hailemariam *et al.*, 2019), where $\varepsilon_j \approx MVN(0, \Gamma)$. The symmetric variance-covariance matrix Γ can be specified as:

$$
\Gamma = \begin{vmatrix} 1 & \rho_{CD,IV} & \rho_{CD,SWC} & \rho_{CD,LLD} \\ \rho_{IV,CD} & 1 & \rho_{IV,SWC} & \rho_{IV,LLD} \\ \rho_{SWC,CD} & \rho_{IV,SWC} & 1 & \rho_{SWC,LLD} \\ \rho_{LLD,CD} & \rho_{LLD,IV} & \rho_{LLD,SWC} & 1 \end{vmatrix} \tag{6}
$$

The correlation matrix's off-diagonal elements, $\rho_{jn,}$ represent the correlation between the stochastic components of different adaptation strategies (Hailemariam *et al.,* 2019). Hence, Equation (6) generates an MVP model that jointly represents decisions to adopt a particular adaptation strategy.

3.3.2.2. Modeling the impact of adaptation to climate change on the farm household's farm income and downside risk exposure.

Modeling the impact of adaptation measures to climate change and variability of household's farm income and downside risk exposure under the ESRM framework proceeds in two stages (Hailemariam *et al*., 2013; Di Falco, 2014; Gorst *et al.,* 2015; Menale *et al.,* 2015; John *et al*., 2017; Wekesa *et al.,* 2018; Issahaku and Abdulai, 2020). A selection model of multiple climate change adaptation strategies is estimated in the first stage. In this stage, farm households are assumed to face a choice of possible combinations of climate change adaptation practices in response to changes in climate and variability.

In the context of climate change adaptation strategies, one can define the latent variable $G^*{}_{ij}$ as a representation of the expected utility derived from adopting a specific adaptation strategy j $(j = 1 \ldots J)$ compared to an alternative strategy k. This variable captures the expected farm income and the downside risk exposure associated with the chosen adaptation strategy. The formulation can be expressed as:

$$G^*{}_{ij} = X_{ij}\varphi_j + \varepsilon_{ij} \tag{7}$$

The deterministic component X_i represents a vector of exogenous variables supposed to influence the likelihood of choosing strategy j, such as household characteristics, resource constraints and market access, institutional factors, farm plot characteristics, climate change perception, and shock variables. φ denotes the vector of parameters indicating the magnitude and direction of each explanatory variable's effect on the decision to adopt. The error term ε_{ij} captures unobserved characteristics, and $E(\varepsilon_{ij}|X_i) = 0$; the covariate vector X_i is uncorrelated with the idiosyncratic unobserved stochastic component ε_{ij}.

The farmer's farm income and downside risk exposure from choosing a particular adaptation strategy is not observable, but one can observe the choices of adaptation strategy in the form of a set of binary variables. Let G_i a criterion function that determines which regime the household faces, such that:

$$G_i = \begin{cases} 1 \;\; iff \;\; G^*{}_{i1} > \max\limits_{k \neq j}(G^*{}_{ik}) \;\; or \;\; \varepsilon_{i1} < 0 \\ \quad\quad\quad\quad\quad\quad \vdots \quad\quad\quad\quad\quad\quad\quad\quad\quad\quad for \; all \; k \neq j \\ J \;\; iff \;\; G^*{}_{iJ} > \max\limits_{k \neq J}(G^*{}_{ik}) \;\; or \;\; \varepsilon_{iJ} < 0 \end{cases} \quad (8)$$

Where $\varepsilon_{ij} = \max\limits_{k \neq j}(G^*{}_{ik} - G^*{}_{ij}) < 0$ (Bourguignon *et al.*, 2007). It implies that farm household i will choose to adapt ($G_i = 1$) some strategies in response to change in climate and variability if strategy j provides greater expected welfare than any other strategy, $k \neq j$, that is if $\varepsilon_{ij} = \max\limits_{k \neq j}(G^*{}_{ij} - G^*{}_{ik}) > 0$.

Assuming that ε_{ij} is independently Gumbel distributed, that is, under the independence of irrelevant alternatives (IIA) hypothesis, the probability of farmer i with a set of characteristics X choosing adaptation strategy from j leads to a multinomial logit model (McFadden, 1973), where the probability of choosing strategy $j(P_{ij})$ is

$$P_{ij} = P\big(\,\varepsilon_{ij} < 0|X_i\big) = \frac{exp(X_i\varphi_j)}{\sum_{k=1}^{J} exp(X_i\varphi_k)} \quad (9)$$

The maximum likelihood method can be used to estimate the parameters of the latent variable model.

In the second stage of the ESRM, the impact of each strategy on the household's farm income and downside risk exposure is estimated through the Bourguignon *et al*. (2007) multinomial selection-bias correction model. Farm households face a total of J regimes in this stage, with regime $j = 1$ being the reference category (non-adapting). In the remaining set ($j = 2 \ldots J$), at least one form of adaptation strategy is adopted. The household's farm income and downside risk exposure for each possible regime is defined as:

$$Regime \;\; 1\text{: } Y_{i1} = \alpha_1 H_{i1} + \omega_{i1} \quad\quad if \; G_i = 1 \quad (10a)$$

$$\vdots \quad\quad\quad\quad \vdots \quad\quad\quad\quad j = 2 \ldots M$$

$$Regime \;\; M\text{: } Y_{ij} = \alpha_j H_{ij} + \omega_{ij} \quad\quad if \; G_i = J \quad (10m)$$

Where Y denotes the farm household's welfare, using the logs of farm income and downside risk exposure as a welfare indicator of the i^{th} farmer in regime j, H represents a vector of explanatory variables that are hypothetically the determinants of farm incomes and downside risk exposure included in X_i. The error term ω captures the unobserved characteristics, which substantiates $E(\omega_{ij}|H_i, X_i) = 0$ and $Var(\omega_{ij}|H_i, X_i) = \sigma^2{}_j$.

The outcome variables are only observed if and only if one of the possible adaptation strategy combinations is used (Hailemariam *et al.,* 2013; Di Falco and Veronesi, 2013). Unobservable factors that affect the probability of adopting strategies may also have an impact on farm income and downside risk exposure, resulting in non-zero covariances between the error terms of the decision to adapt equation ε_{ij} and the outcome equation, ω_{ij}. As a result, the error terms in Equation (10a-10m) have non-zero expected values, and OLS estimates will not be reliable if they are not based on consistent data. Consistent estimation of β*m* requires the inclusion of the selection correction terms of the choices in Equation 10a-10m. Following (Di Falco and Veronesi, 2013), the selectivity term or inverse mills ratio (IMR) (which can be computed from Equation 9) can be defined as:

$$\lambda_j = \sum_{k \neq j}^{J} \rho_j \left[\frac{\hat{P}_{ik} \ln(\hat{P}_{ik})}{1 - \hat{P}_{ik}} + \ln(\hat{P}_{ij}) \right] \quad (11)$$

Where ρ is the correlation between ε and ω. There are $J - 1$ selection bias correction terms to be included in the multinomial choice setting; one is for each alternative package.

Following Bourguignon *et al*. (2007), this study estimates the following selection bias-corrected farm income equations by incorporating the selectivity terms λ into Equation (10) to obtain consistent estimates of α_1 in the outcome Equations (10a-10m):

$$Regime\ 1\colon\ Y_{i1} = \alpha_1 H_{1i} + \sigma_1 \hat{\lambda}_{1i} + \upsilon_{i1} \qquad if\ G_i = 1 \quad (12a)$$

$$\vdots \qquad\qquad \vdots$$

$$Regime\ J\colon\ Y_{iJ} = \alpha_J H_i + \sigma_J \hat{\lambda}_{Ji} + \upsilon_{iJ} \qquad if\ G_i = J \quad (12m)$$

Where υ the error term with $E(\upsilon) = 0$, σ is the covariance between ε and ω, and ρ is the correlation between ε and ω. There are $J - 1$ selection bias correction terms to be included in the multinomial choice setting; one is for each alternative package.

Counterfactual Analysis and Treatment Effects

The counterfactual analysis specifies, in the absence of a self-selection problem, what would have happened to adapters of climate change had they not adapted. However, the same farm households cannot be observed in two distinct situations, being adapters and non-adapters at the same time. Following Bourguignon *et al*. (2007), Di Falco (2014), and John *et al.* (2017), the multinomial endogenous switching regression model is applied to produce selection-corrected predictions of counterfactual farm income and downside risk exposure. Using equation (8) and following the approach of Carter and Milon (2005), this study computes the expected farm income and downside risk exposure for farm households in both the actual and counterfactual scenarios.

The observed outcomes for adapters (actual)

$$E\left[Y_{i2}\middle|G_i = 2, H_{i2}, \hat{\lambda}_{i2}\right] = \alpha_2 H_{i2} + \sigma_{2i\varepsilon}\hat{\lambda}_{i2} \quad (13a)$$

$$\vdots \qquad\qquad\qquad \vdots$$

$$E\left[Y_{iJ}\middle|G_i = J, H_{iJ}, \hat{\lambda}_{i,J}\right] = \alpha_J H_{iJ} + \sigma_{J\varepsilon}\hat{\lambda}_{iJ} \quad (13m)$$

Similarly, the Equation for the adopters had they decided not to adopt any form of adaptation strategy (counterfactual):

$$E\left[Y_{i1}\middle|G_i = 2, H_{i2}, \hat{\lambda}_{i2}\right] = \alpha_1 H_{i2} + \sigma_{i1\varepsilon}\hat{\lambda}_{i2} \quad (14a)$$

$$\vdots \qquad\qquad\qquad \vdots$$

$$E\left[Y_{i1}\middle|G_i = J, H_{iJ}, \hat{\lambda}_{i,J}\right] = \alpha_1 H_{iJ} + \sigma_{i1\varepsilon}\hat{\lambda}_{iJ} \quad (14m)$$

Moreover, the average treatment effect on the treated (ATT), which captures the average adoption effect (average impact on farm income and the downside risk exposure), can be calculated using the difference between equations (13a) and (14a) or equations (13m) and (14m).

$$ATT = E\left[Y_{i2}\middle|G_i = 2, H_{i2}, \hat{\lambda}_{i2}\right] - E\left[Y_{i1}\middle|G_i = 2, H_{i2}, \hat{\lambda}_{i2}\right]$$
$$= H_{i2}(\alpha_2 - \alpha_1) + \hat{\lambda}_{i2}(\sigma_{i2} - \sigma_{i1}) \quad (15)$$

The first term on the right-hand side of Equation (15) denotes the expected change in adopters' mean outcome if they had the same characteristics as non-adopters. The second term ($\hat{\lambda}_{ij}$) is the selection term that captures all potential effects of differences in unobserved variables.

Estimation of farm income moments: A moment approach to evaluating downside risk

In line with previous studies, this research employs a moment-based approach to assess farmers' exposure to risks (Di Falco and Veronesi, 2018; Emily *et al.,* 2019). This approach utilizes the sample moments of farm returns to capture skewness, which is the third central moment.

The farm income function under risk is specified as:

$$y = g(Z, X, e) \tag{16}$$

Where y represents the farm income of the household head, Z is the vector of socioeconomic variables, X is the vector of inputs that may influence farm production, and e is a vector of random variables representing uncontrollable factors affecting output, such as extreme weather events and fluctuations in temperature and rainfall.

As previously discussed, this study assesses the probability distribution of the farm income function$g(Z, X, e)$ by applying the moment-based approach proposed by Di Falco and Veronesi (2018). Here, risk exposure is represented by the moments of the farm income function. Consider the following econometric specification for $g(Z, X, e)$:

$$g(Z, X, e) = f_1(Z, X, \beta) + \mu \tag{17}$$

Where $f_1(.) \equiv E[g(Z, X, e)] \equiv E(y)$ is the expected farm income, which corresponds to the first central moment. The term $\mu = g(Z, X, e) - f_1(Z, X, \beta)$ is a random variable with a mean of zero, whose distribution is exogenous to farmers' actions. The higher moments of $g(Z, X, e)$ are given by:

$$\{[g(Z, X, e) - f_1(Z, X, \beta)]^i | X\} = f_i(Z, X, \beta_i) \; for \; i = 2,3 \tag{18}$$

This indicates that $f_2(Z, X, \beta_2)$ represents the second central moment, or variance, while $f_3(Z, X, \beta_3)$ signifies the third central moment, or skewness. This approach offers a flexible framework for analyzing the impacts of household characteristics, resource constraints, market access, institutional factors, farm plot characteristics, climate change perceptions, and past climatic shocks on the distribution of farm income amidst production uncertainty. An increase in skewness suggests a reduction in downside risk exposure, thus decreasing the probability of crop failure or loss of farm income. Mitigating downside risk entails reducing the asymmetry (or skewness) of the risk distribution toward favorable outcomes, while holding both the mean and variance constant (Di Falco and Veronesi, 2018).

3.3.2.3. Modelling the impact of adaptation to climate change on the household's vulnerability to food insecurity

This study uses a METE model to examine the impact of climate change adaptation strategies on a household's vulnerability to food insecurity. Just like it was earlier explained in the MESR framework, METE is also modelled simultaneously in two stages (Deb and Trivedi, 2006). In first stage, farm households are assumed to face a choice of possible combinations of climate change adaptation practices in response to changes in climate and variability. Consider the latent variable ${G^*}_{ij}$ that captures the expected welfare outcomes (vulnerability to food insecurity) derived from adopting climate change adaptation strategy j $(j = 1 \dots J)$ instead of implementing other strategy k. It is specified as:

$$ {G^*}_{ij} = X_{ij}\varphi_j + \sum_j^J \delta_i l_{ij} + \varepsilon_{ij} \tag{19} $$

The deterministic component X_i represents a vector of exogenous variables influencing the likelihood of choosing strategy j, such as household characteristics, resource constraints and market access, institutional factors, farm plot characteristics, climate change perception, and shock variables. The vector of parameters φ indicates the magnitude and direction of each explanatory factor's effect on the decision to adopt. The error term ε_{ij} captures unobserved characteristics, and $E(\ \varepsilon_{ij} | X_i) = 0$; the covariate vector X_i is uncorrelated with the idiosyncratic unobserved stochastic component ε_{ij}. There is also a latent factor, known as l_{ij}, that takes into account the hidden characteristics that influence a household's decision-making and outcomes. These characteristics include the farmers' management and technical abilities in understanding how to respond to climate change.

Following Deb and Trivedi (2006), we let $j = 0$ denote nonadopters, and ${G^*}_{i0} = 0$ is not observed; we observe the choice of climate change response in the form of a set of binary variables $d_i = (d_{i1,} d_{i2,} d_{i3,} \dots, d_{iJ})$. Similarly, we let the corresponding latent factors $l_i = (l_{i1,} l_{i2,} l_{i3,} \dots, l_{iJ})$. Then, the factors influencing the choice of climate change adaptation strategies are estimated as:

$$ P_r(d_i | X_i l_i) = g(\acute{X}_i\varphi_1 + \sum_j^J \delta_{1j} l_{ij} + \acute{X}_i\varphi_2 \sum_j^J \delta_{2j} l_{ij} \dots + \acute{X}_j\varphi_j\ \sum_j^J \delta_{Jj}\, l_{ij} \tag{20} $$

Where g is an appropriate multinomial probability distribution with a mixed multinomial logit (MMNL) structure stated as:

$$P_r(d_i|X_i l_i) = \frac{exp(\acute{X}_i\varphi_j+\delta_i l_{ij})}{1+\sum_{j=1}^{J} exp(\acute{X}_i\varphi_j+\delta_i l_{ij})} \quad (21)$$

The maximum likelihood method can be used to estimate the parameters of the latent variable model.

In the second stage, the METE model is used to look at how different climate change adaptation practices affect vulnerability to food insecurity**.** Following Issahaku *et al.* (2021), Khonje *et al.* (2018), and Abreu *et al.* (2015), the expected outcome equation for individual j is stated as follows:

$$E(VFI_i = 1|z_i, d_i, l_i) = z_i\vartheta + \sum_{j=1}^{J} d_i\gamma + \sum_{j=1}^{J} l_i\tau \quad (22)$$

Where VFI_i is the vulnerability to food insecurity status of the household i measured by $\widehat{V_h}$ as household vulnerability coefficient; $VFI_i = 1$ if $\widehat{V_h}$ is greater than or equal to 0.5; z_i represents exogenous covariates with parameter vectors ϑ; and parameter γ represents how any adaptation strategy affects vulnerability to food insecurity compared to not adapting. More specifically, coefficients γ show how climate change adaptation strategies affect vulnerability to food insecurity.

Unobserved characteristics that might also affect the choice of treatments (farmers' decision to adopt an adaptation strategy) are affecting the outcome variables to the extent that $E(VFI_i = 1|z_i, d_i, l_i)$ is a function of the latent factors l_i (Issahaku *et al*., 2021; Khonje *et al.,* 2018). It is important to note that if the factor-loading parameter (τ) is positive, a positive correlation exists between adopting climate change adaptation strategies and outcomes through unobservable characteristics, indicating positive selection. Conversely, if the factor-loading parameter is negative, these two variables correlate negatively, indicating negative selection (Deb and Trivedi, 2006; Issahaku *et al.,* 2021).

For the METE model to be identified, Deb and Trivedi (2006) recommend using at least one selection instrument that affects the adaptation decisions of farming households but does not affect the outcome variables among the households. However, finding an instrumental variable is tedious and challenging in empirical analysis (Asmare *et al.,* 2019). A simple falsification test on the excluded instruments, i.e., distance to market, climate information, and climate change perception (Di Falco and Veronesi, 2013; Menale *et al.,* 2015; John *et al.,* 2017), was conducted. Through this test, the instruments influence the adoption of climate change adaptation strategies in all cases but not consumption per adult equivalence. The model estimation utilized the *mtreatreg* command within the STATA software package. This particular command ensured the precise and accurate estimation of the model.

Measuring household level of vulnerability to food insecurity

Following Ayalneh (2012), Stanley *et al.* (2015), Million *et al.* (2019), and Fassil and Adem (2021), this study follows the vulnerability as expected poverty (VEP) approach to measure the household's level of vulnerability to food insecurity. According to Christiaensen and Subbarao (2005), the VEP approach focuses on the probability that a household becomes poor in the future if it is currently not poor or continues to be poor if it is currently poor. Accordingly, this method estimates the probability of households becoming food insecure using consumption expenditure per adult equivalent (FCEAE) as a measure of household welfare.

The vulnerability level of household h to food insecurity in time t as $V_{h,t}$ gives the probability that the household will find itself consumption poor in time $t+1$, such that:

$$V_{h,t} = \Pr\left(C_{h,t+1} \leq z\right) \tag{23}$$

Where $C_{h,t+1}$ is the FCEAE (welfare indicator) level of the household h in time $t+1$, and z is the food poverty line, which represents the value of food appropriate to meet the recommended minimum daily calorie requirement of 2200 kilocalories per adult equivalent (i.e., food security threshold).

Following Christiaensen and Subbarao (2005), the FCEAE of the farming household is a function of a vector of some observed and unobserved characteristics and is given as follows:

$$lnC_h = X_h\beta + \varepsilon_h, \tag{24}$$

Where C_h refers to consumption expenditure per adult equivalent for the household, X_h represents a bundle of observable household characteristics, β is a vector of parameters to be estimated, and ε_h is a mean-zero disturbance term that captures personal factors (shocks) that contribute to different per-capita values of food consumption in different households that are otherwise observationally equivalent (Stanley *et al*., 2015).

Furthermore, it is assumed that the variance of the unexplained part of FCEAE ε_h depends on household $h's$ on the farm and household socioeconomic characteristics:

$$\sigma^2{}_{\varepsilon,h} = X_h\theta + \omega_h \tag{25}$$

Where θ denotes a vector of parameters to be estimated, ω_h is the vector of residuals of this second estimation. However, estimates of β and θ with the usual regression technique violate the assumption (homoscedasticity) of the ordinary least square method. Following Christiaensen and Subbarao (2005), Chaudhuri *et al.* (2002), and Ayalneh (2012), a three-step feasible generalized least squares (FGLS) method of estimation is used to obtain a consistent estimate of β and θ.

To begin, the estimation of Equation (24) is necessary, which can be achieved through the Ordinary Least Squares (OLS) method. Once that is done, Equation (25) can be estimated using OLS as well, where the squared residuals from the previous estimation are used as the dependent variable. These predictions are then applied to re-estimate Eq. (25) through OLS, with each residual assigned a weight based on $X_h\theta$:

$$\frac{\varepsilon^2{}_{OLS,h}}{X_h\hat{\theta}_{OLS}} = \left[\frac{X_h}{X_h\hat{\theta}_{OLS}}\right]\theta + \frac{\omega_h}{X_h\hat{\theta}_{OLS}} \tag{26}$$

This transformed Equation is estimated using OLS to obtain an asymptotically efficient FGLS estimate, $\hat{\theta}$ FGLS. According to Chaudhuri *et al.* (2002), $X_h\hat{\theta}_{FGLS}$ is a consistent estimate of the variance of the idiosyncratic component of household consumption ($\sigma^2{}_{\varepsilon,h}$). The standard deviation of the variance can be calculated using the following equation:

$$\hat{\sigma}_{\varepsilon,h} = \sqrt{X_h\hat{\theta}_{FGLS}} \tag{27}$$

The variance derived from Equation (24) is utilized to adjust Equation (27) in order to account for heteroscedasticity. The specified form of the consumption function assumes homoscedasticity and is presented as follows:

$$\frac{lnC_h}{\hat{\sigma}_{\varepsilon,h}} = \frac{X_h}{\hat{\sigma}_{\varepsilon,h}}\beta + \frac{\varepsilon_h}{\hat{\sigma}_{\varepsilon,h}}$$

$$lnC_h{}^* = X_h{}^*\beta + \varepsilon_h{}^* \tag{28}$$

OLS estimates of Equation (28) yield unbiased, consistent, and asymptotically efficient estimates of β. Then, the expected log household's food consumption expenditure per adult equivalent per day for each household is generated by using Equation (29) given as:

$$\hat{E}\{lnC_h|X_h\} = X_h\hat{\beta} \tag{29}$$

The variance of log food consumption expenditure for each household is as follows:

$$\hat{\psi}\{lnC_h|X_h\} = \hat{\sigma}_{\varepsilon,h} = X_h\hat{\theta} \tag{30}$$

Assuming that per adult equivalent food consumption distributes log-normally (Gaiha and Imai, 2008; and Günther and Harttgen, 2009), each household's probability of food insecurity shortly (say, at time $t + 1$) will be given by:

$$\widehat{V_h} = \hat{P}(lnC_h < lnz\,|X_h) = \emptyset\left(\frac{lnz - lnX_h\hat{\beta}}{\sqrt{X_h\hat{\theta}}}\right) \tag{31}$$

Where ∅ (.) denotes the cumulative density function of the standard normal distribution; z is the prescribed threshold per adult equivalent value of food consumed to meet the minimum energy requirement (i.e., food poverty line); $\widehat{V_h}$ is a set of estimates, one for each household, and represents the probability that each household faces falling below the minimum energy requirement in the future. Its value lies between 0 and 1. When $\widehat{V_h} = 0$, a household's per capita value of food consumed will be adequate to meet the minimum amount of calories required, and when $\widehat{V_h} = 1$, the value of food consumed will be lower than the prescribed threshold.

Some analysts (e.g., Chaudhuri *et al.,* 2002; Capaldo *et al.,* 2010) have attempted to draw fine distinctions between vulnerable households as those with an estimated vulnerability coefficient above or equal to 0.5 and non-vulnerable otherwise. This study will follow the same procedure to classify vulnerable and non-vulnerable households in the study area depending on the values of $\widehat{V_h}$. Those households with $a\,\widehat{V_h}$ greater than or equal to 0.5 are vulnerable to food insecurity and, otherwise, if not vulnerable.

Following Ayalneh (2012) and Million *et al.* (2019), the current household food insecurity status can be determined by the amount of money required to achieve the daily minimum dietary requirement. In this study, therefore, 2,200 kcal per day per adult equivalent is used as the food poverty line (threshold) fixed by Ethiopia's government (MoFED, 2002). Thus, households are deemed food insecure if the amount of money they spend on food is insufficient to purchase an essential diet that is nutritionally adequate (Million *et al.,* 2019).

3.3.2.4. Quantile moment approach: To evaluate the cost of risk

It is crucial for farmers to make investments in adopting adaptive practices, which are strategies designed to adjust to or mitigate the adverse effects of climate change and strengthen their resilience. These practices could include changes in crop management practices, soil and water conservation measures, or livelihood portfolio diversification strategies. However, putting these measures into action involves financial considerations, such as investing in new technologies, infrastructure, training, and higher operational expenses. There may also be potential losses for farmers who have to give up other profitable activities or crops. Nevertheless, it is important to consider the costs in relation to the potential advantages, such as enhanced resilience, decreased losses from extreme events, heightened productivity, and long-term sustainability (Menale *et al.,* 2015; Kim *et al.,* 2014).

Building on the work of Menale *et al.* (2015), Kim *et al.* (2014), and Chavas and Kim (2015), this study used a quantile-based approach to look into the cost of risk or the risk premium for both adapters and non-adapters. The study utilized quartiles (4 quantile groups) to examine the impact of different climate change adaptation strategies on the cost of risk: $K = 4$. The first quantile represents the interval (0, 0.25] of the payoff distribution, the second (0.25, 0.5], the third (0.5, 0.75], and the fourth (0.75, 1.0], respectively. This approach strikes a balance between simplicity (with $K = 4$ not being excessively large, reducing the estimation burden) and a more nuanced analysis of risk (Kim *et al.,* 2014).

This study examines the cost of risk evaluation within an expected utility[3]framework. It takes into account the use of constant relative risk aversion (CRRA) utility functions, represented by the equation $\mathrm{U(Y)} = (1 - \mathrm{b})^{-1}\mathrm{Y}^{(1-\mathrm{b})}$, where $\mathrm{Y} > 0$ is the farm income and $\mathrm{b} > 0$ is the relative risk aversion coefficient. It satisfies risk aversion (with $\mathrm{U}''(\mathrm{Y}) < 0$) and downside risk aversion

[3] It stated that when making decisions under uncertainty, individuals always strive to maximize *EU(a),* where *E* represents the expectation operator based on the subjective probability distribution.

(with $U''(Y) > 0$). When taking risk aversion into account, all pertinent moments of the farm's income distribution have an impact on the risk premium R:

$$R \approx 0.5 * [F(b_k) - F(b_{k-1})] * \left\{ \frac{b(m_{k1})^{-b-1}}{\sum_{i=1}^{k}\{[F(b_k) - F(b_{k-1}) * (m_{k1})^{-b}]\}} * m_{k2} + [b(M_1)^{-1}] * [m_{k1} - M_1]^2 \right\} + (1/6) * [F(b_k) - F(b_{k-1})] * \left\{ - \frac{b(1+b)(m_{k1})^{-b-2}}{\sum_{i=1}^{k}\{[F(b_k) - F(b_{k-1}) * (m_{k1})^{-b}]\}} * m_{k3} - [b(1+b)(M_1)^{-2}] * [m_{k1} - M_1]^3 \right\} \quad (32)$$

Where m_{k1}, m_{k2}, and m_{k3} represent the partial mean, variance, and skewness of farm income distribution, respectively, in quantile K. The probability of each partial central moment being in quantile K is determined by $[F(b_k) - F(b_{k-1})]$. This is done using a multinomial logit model applied across all four quantiles. M stands for the overall central moment. Before $1/6$, the terms used pertain to the cost of risk linked to the variance. This implies that when risk aversion is present, an increase in the variance of farm income generally leads to a rise in the private cost of bearing that risk. Similarly, all terms starting from $1/6$ represent the cost of risk related to the skewness component. This suggests that the risk premium tends to decrease as skewness increases, assuming a preference for avoiding downside risk (Di Falco and Chavas, 2009; Menale *et al.,* 2015*;* Kim *et al.,* 2014*)*.

3.4. Definition of Variables and Working Hypotheses

3.4.1. Determinants of farmers' adaptation decisions to climate change

Dependent variable

In the empirical estimation, the selection of an existing adaptation option was considered as the dependent variable. Many farmers in the study area have made significant adjustments to their management strategies in order to adapt to the increasingly rapid pace of climate change. As per the MVP model, the dependent variables consist of four dummy variables that represent the utilization of crop diversification, adoption of improved crop varieties, soil and water conservation, and livelihood portfolio diversification. Thus, each binary observed adaptation practice is assigned a value of 1 if and only if the farmers choose to implement a specific climate change adaptation strategy, and it is assigned a value of 0 if they do not.

Crop diversification: Another practice that can be implemented is crop diversification, which aims to minimize the risks associated with complete crop failure instead of solely focusing on maximizing the yields of a single crop (UNEP, 2006). Diversification is considered a coping strategy that has developed to address anticipated variations in rainfall and seasonal fluctuations in rainfall patterns (Lin, 2011). It is also frequently employed in Ethiopia to mitigate the effects of climate change and variability (Temesgen *et al.,* 2009). There are numerous advantages associated with crop diversification. The enhanced security of this approach stems from the fact that even in the event of failure of one crop variety, farmers are likely to have other successful varieties at their disposal. In addition, implementing a crop rotation system can effectively preserve soil fertility and prevent soil depletion (Maddison, 2006).

Improved crop varieties: are bred to be more resilient to extreme weather events such as droughts, floods, and heatwaves, which are expected to become more frequent and intense with climate change. These varieties have a higher tolerance for stressors compared to traditional varieties, resulting in a more consistent yield even in difficult conditions. Past empirical studies have also indicated that the implementation of enhanced crop varieties and agricultural practices are effective farm-level adaptation strategies to mitigate the anticipated effects of climate change in Ethiopia (Gebrehiwot *et al.,* 2020; Melese, 2019; Hailemariam *et al.,* 2013).

Soil and water conservation measures: Refer to a set of practices and strategies to prevent soil erosion, improve water management, and sustain the health and fertility of agricultural lands. These measures typically include organic manure contour plowing, terracing, cover cropping, mulching, stone walls, and soil bunds on private field plot levels. Several research studies (Tadele *et al.,* 2014; Million *et al.,* 2019) show that conserving soil and water helps keep the soil's fertility and nutrient levels essential for plant growth. This is particularly important in the face of extreme weather events, such as heavy rainfall or more extended drought periods, which are expected to increase with climate change. Million *et al.* (2019) also reported that taking steps to protect soil and water positively affects the amount of money spent on food per person and the net value of crops. It also makes it much less likely for farmers to be food insecure. This includes being at risk of food insecurity as well as being in a state of temporary or long-term food insecurity.

Livelihood portfolio diversification strategies: Refer to engaging in various activities or sources of income to reduce dependence on the agricultural sector. It comprised practices such as non-farm rural wage or petty trades (excluding the sale of natural resources), crafts/small industry, services, rents, food and drink processing, and remittances. Livelihood diversification enables rural households to devise other means to promote their income level and minimize their susceptibility to different livelihood shocks (Baird *et al.,* 2014). By diversifying their sources of income, subsistence farmers can better withstand the adverse effects of climate change and significantly reduce their likelihood of falling into poverty (Amogne *et al.,* 2017).

Explanatory variables

The choice of exogenous variables used in this study is based on theoretical and empirical climate change adaptation-related literature and impact evaluation studies (Hailemariam *et al.,* 2013; Di Falco, 2014; Menale *et al.,* 2015; John *et al*., 2017; Wekesa et al., 2018; Issahaku and Abdulai, 2020). These variables may explain the general adoption of climate change adaptation and the choice of specific adaptation methods. The explanatory variables reflected in this study comprise socioeconomic, resource constraints and market access, institutional and infrastructural factors, farm plot characteristics, climate change perception, and shock indicator variables.

Socioeconomic factors

Gender of the household head: A dummy variable takes one if the household head is male and 0 if female. Gender is supposed to influence the decision to take adaptation measures. However, the effect of gender on perception and adaptation to climate change is mixed. Some previous studies on adaptation (Dolisca *et al.,* 2006; Bayard *et al.,* 2007; Nhemachena and Hassan, 2007) found female farmers more likely to adopt adaptation practices than their counterparts. The authors commonly argue that women perform much agricultural work in rural smallholder farming communities. Thus, women have more farming experience and information on various management practices and other factors, such as markets and the food need of households. Interestingly, however, there is the opposite view that male-headed households are more likely to adapt than female-headed ones. This is mainly because cultural and social barriers make it harder for women to get land and learn about crop management practice (Abay and Assefa, 2004; Temesgen *et al.,* 2011; Dereje and Assefa, 2016; Waibel *et al.,* 2018; Paulos and Belay, 2018). The latter argument, however, is in line with this study because male-headed households perform the majority of agricultural tasks and other institutional roles in the study area.

Age: It is a continuous variable measured in years and refers to the household head's age during the interview. There is no consensus in the adoption literature on the influence of the age of the household head on the decision to adapt. Some empirical evidence has shown that age can positively influence the decision to adapt. It implies that the likelihood of adopting adaptation strategies is more highly practiced among older farmers than younger ones. Older farmers have more experience, which helps them perceive the adverse effects of climate change and variability (Apata, 2011; Temesgen *et al.,* 2011; Gutu *et al.,* 2012; Paulos and Belay, 2018). On the other hand, age can be found to have a negative influence on perception and adaptation decisions (Solomon *et al.,* 2016; Denkyirah *et al.,* 2017; Waibel *et al.,* 2018; Ojo and Baiyegunhi, 2019). Because of their shorter planning horizons, older farmers are more risk-averse than younger farmers and, thus, less likely to adapt to climate change. Thus, in this study, age is hypothesized to have either positive or negative impacts on the choice of adaptation decision of farm households.

Family size: Refers to the number of people currently living with the household head. Empirical studies on climate change adaptation strategies show that family size has an ambiguous influence on the decision to adapt. As a proxy for labor accessibility, household size may influence labor accessibility positively since its availability eases labor constraints (Anley *et al.,* 2007; Gbetibouo, 2009; Apata, 2011; Gutu *et al.,* 2012; Abid *et al.,* 2015; Ali and Erenstein, 2016; Abraham *et al.,* 2017; Paulos and Belay, 2018; Ojo and Baiyegunhi, 2019). On the other hand, some previous literature on adaptation (Chilot, 2007) has found that a large family might be forced to turn away part of its labor force into non-farm activities to generate more income. However, this study aligns with the first argument, which indicates that most adaptation measures undertaken by farmers are more labor-intensive. Hence, family size has a positive influence on adopting adaptation strategies.

Education: Refers to the education level of the household head. It is a categorical variable coded as =0 (reference category) if illiterate, 1 if primary, 2 if secondary, and 3 if post-secondary. The effect of education on adaptation to climate change and variability is unambiguous. Education is assumed to increase the probability of accessing advanced information regarding climate change adaptation measures (Apata, 2011; Abid *et al.,* 2015). Evidence from empirical studies justifies that education is an essential factor that positively influences the decision to adapt to climate change (Abraham *et al.,* 2017; Abayineh and Belay, 2017; Paulos and Belay, 2018; Waibel *et al.,* 2018; Ojo and Baiyegunhi, 2019). Accordingly, in this study, the household head's education level is expected to positively affect adaptation to climate change.

Resource constraints and market access

Livestock ownership: Refers to the number of different species of livestock owned by the household, measured in tropical livestock units (TLU). Previous studies show livestock ownership positively correlates with adaptation measures (Yesuf *et al.,* 2008; Temesgen *et al.,* 2009; Aemiro *et al.,* 2012). Alem *et al.* (2016) also pointed out that the total number of livestock owned by the household significantly increased the probability of using soil and water conservation and other crop management as adaptation options. Abraham *et al.* (2017) came up with findings that point to a positive and significant association between adopting climate change adaptation strategies such as adjusting the planting season, integrating crops with livestock rearing, and soil and water conservation practices. However, some empirical studies (Fentiel *et al.,* 2013; Million *et al.,* 2019) have shown that more significant livestock holdings negatively influence the adoption of soil bunds and bench terracing. According to their argument, households with more extraordinary livestock holdings concentrated more on livestock than crop production. Since livestock and crop production are the primary sources of livelihood and are considered assets in the study area, households with better resource endowments are more likely to undertake adaptation measures.

Farm size: Refers to the total land area a farm household holds in a hectare. Several studies have reported mixed effects of farm size on adaptation to climate change and variability. For example, a study by Gbetibouo (2009) and Abid *et al.* (2015) found that farm size positively and significantly affects adaptation to climate change. In line with this, Gutu *et al.* (2012) and Alem *et al.* (2016) also showed that an increase in the land area increases the probability of using more adaptation strategies. Other studies found that farm size is negatively and significantly related to farmers' adaptation decisions (Kurukulasuriya and Mendelsohn, 2006; Temesgen *et al.,* 2011). Moreover, Paulos and Belay (2018) revealed that the incidence of adaptation to climate change decreases with cultivated land size. This is because of the need for a plot-specific adaptation rather than the size of the land. However, this study contends with the former argument, which indicated that farmers with large farms would adopt measures requiring a large area of land.

Institutional and infrastructural factors

Frequency of extension contact: It refers to the frequency of formal extension visits in the cropping season. A dummy variable takes the value of 1 if the farmer contacts the extension agent at least six times per year and zero otherwise. According to the Ethiopian Agricultural Extension Manual, it is stipulated that every farmer is entitled to receive guidance and technical help from allocated agents at a minimum frequency of once per month (MoA (Ministry of Agriculture), 2010). As per the guidelines, farmers who receive technical advice and help on at least six occasions during a year are referred to as having accessed extension services.

As a source of information, extension services help farmers better understand the adverse effects of climate change and its adaptation strategies. Many empirical shreds of evidence (Apata, 2011; Gutu *et al.,* 2012; Bryan *et al.,* 2013; Alem *et al.,* 2016; Abayineh and Belay, 2017; Ojo and Baiyegunhi, 2019) revealed that extension visits to the household have a positive effect on adaptation decisions. It could be apparent that access to advisory support through extension services improved farmers' understanding of climate change and the context to which they must adapt. Thus, this study expects that farmers will have more contact with extension personnel and services, make better comparative decisions among alternatives, and choose the best strategy that can be implemented to deal with climatic extremes.

Access to credit: It is a dummy variable, which takes the value one if the farm household has access to credit and 0 if the household has no access to credit service. The provision of saving and credit services is widely recognized as a crucial factor in enhancing the adaptive ability of farmers by facilitating saving and wealth building. Nhemachena and Hassan (2007) argue that the availability of affordable credit enhances the financial capacity of farmers, enabling them to cover transaction costs connected with different adaptation strategies they may wish to undertake.

Several studies in Ethiopia have shown that access to credit is a significant determinant of the decision to adopt climate change adaptation strategies (Solomon *et al.,* 2012; Gutu *et al.,* 2012; Alem *et al.,* 2016; Abayineh and Belay, 2017; Ojo and Baiyegunhi, 2019). Credit availability eases capital and liquidity constraints and allows farmers to buy purchased inputs. Thus, this study postulates that farmers with better credit services will be more likely to undertake adaptation measures.

Membership in a socioeconomic group: Refers to any socioeconomic relationship in which a household head is a member. It is a dummy variable and takes the value of 1 if the farmer is a member of more than two social groups and zero otherwise. Social groups may include local agricultural-related cooperative associations, self-help groups, etc. Several studies have shown that membership in such groups helps farmers get more and better opportunities to learn new agricultural practices and hence choose the ones that enable them to cope better with climate change (Tafa *et al.,* 2009; Piya *et al.,* 2013; Ali and Erenstein, 2016; Mulwa *et al.,* 2017). Moreover, Abayineh and Belay (2017) and Arun and Jun (2019) justified that membership in any farming institution increases the household's exposure and the probability of adaptation. Therefore, this study hypothesizes that membership in any socioeconomic group positively affects the adaptation decision.

Access to climate information: Access to climate information increases awareness about the potential impacts of climate change on different sectors, communities, and individuals. A dummy takes the value 1 if there is access to climate information and zero otherwise. Early warning signs, weather forecasts, pest infestations, input control, cultivation techniques, pest and disease control, and prices are all critical information about climate change (Thornton *et al.,* 2006; IPCC, 2007; Aker, 2011). Substantial studies (Hansen *et al.,* 2011; Phillipo *et al.,* 2015; Dessalegn *et al.,* 2023) have reported that better access to climate information significantly influenced households' decisions to adapt to climate change.

Distance from the local market: A continuous variable measured in walking hours from home to the nearest input and output market. Previous research has shown that the distance to the local market affects the likelihood of a farm adapting. The local market is also vital for farmers to share and gather information (Madison, 2007; Gutu *et al.,* 2012; Khonje *et al.,* 2015; Abid *et al.,* 2015; Abraham *et al.,* 2017). Abayineh and Belay (2017) posited that poor infrastructure development reduces the incentive for farmers to produce surplus production to supply markets using different technologies. This implies that proximity to the market may provide location advantages to farm households to get information about the availability of inputs and outputs in the particular market. Accordingly, this study hypothesizes that farm households near the local market will be more likely to adapt to climate change than farmers far away.

Farm plot characteristics

Soil fertility: Refers to farmers' affirmative perceptions about the fertility of their farm plots. It is a dummy variable that takes the value 1 for good and medium soil quality and 0 otherwise. Previous studies observed that farmers with fertile plots are less likely to take climate change adaptation measures, particularly relatively costly inputs like drought- or disease-tolerant seeds or SWC-like terracing. They are, however, more likely to plant improved crop varieties for higher yields (Di Falco and Veronesi, 2013; Boansi *et al.,* 2017; Mulwa *et al.,* 2017; Hailemariam *et al.,* 2019; Jeetendra *et al.,* 2018; Million *et al.,* 2019). It is, therefore, hypothesized that households with a positive perception of the fertility status of their farm plot are less likely to invest in capital-intensive climate change adaptation strategies.

Plot slope: Refers to the farmer's perception of the plot's slope. A dummy variable takes the value 1 for the farmer who ranked their plot as flat or moderately flat and 0 otherwise. The empirical adoption literature demonstrated that the steepness of the slope may have an impact on decisions regarding soil and water conservation technologies (Hailemariam *et al.,* 2017; Mulwa *et al.,* 2017; Jeetendra *et al.,* 2018). Consistent with this, Sisay *et al.* (2019) and Million *et al.* (2019) also pointed out that gentle slope plots are less susceptible to soil erosion than steep slope plots. Thus, they are assumed to be negatively associated with using SWC practices. Therefore, it is hypothesized that farmers with gently sloped farm plots are generally less likely to adopt the SWC strategy than those with steep slopes.

The extent of erosion on the plot: Refers to farmers' perceptions of the intensity of erosion problems on their farm plots. It is a dummy variable that takes the value 1 if farmland has portions of moderate to severe erosion intensity and 0 otherwise. Research from the past has shown that households that think their farm plot has more erosion problems are more likely to use SWC measures and less likely to use inorganic fertilizer (Issahaku and Abdulai, 2020; Million *et al.,* 2019). This is because SWC measures can benefit farmers by reducing soil erosion, improving water quality, and promoting the formation of natural terraces over time (Solomon *et al.,* 2013). Therefore, it is hypothesized that farmers who perceive severe erosion problems on their farm plots are more likely to adopt SWC measures.

Climate change perception and shock

Perceptions of seasonal climate variables: Farmers' perceptions of local climatic conditions are believed to influence their decision to adopt climate change adaptation strategies. Perception is measured by averaging the absolute values of the five-point Likert scale results, which represent 0 = no change, +1 = increase, −1 = decrease, +2 = highest increase, and −2 = highest decrease. Many empirical studies on climate change and variability revealed that increasing mean annual temperature upsurges the probability of adopting various climate change adaptation strategies (ACCCA, 2010; Temesgen *et al.,* 2011; Komba and Muchapondwa, 2015; Ojo and Baiyegunhi, 2019). In line with this, Nhemachena *et al.* (2014) explained that as temperatures rise, water resources decrease, leading to a high rate of evaporation, which means farmers need to take some steps to adapt. The authors also argued that increasing mean annual precipitation increases the likelihood of adapting to the change through general farm management practices and growing crop varieties. It is thus hypothesized that households that can perceive these changes are more likely to take any adaptation measures.

Perceived severity of risk from climate shocks: It refers to those climatic events perceived by a farm household that outstrip its capacity to cope with them, including events such as drought, floods, animal disease, severe pest damage to crops, and market shocks. In this study, the severity of the risks associated with the shocks is analyzed in qualitative terms. Following Pandey *et al.* (2019), severity is defined as low if no significant harm was done to the household, medium if manageable damage occurred, and high if loss of land or life-threatening events occurred. Accordingly, it is an ordinal variable that takes 0 for low, 1 for medium, and 2 for high for the severity of the shocks that the household experienced. The empirical literature on climate shocks and responses has shown that farm households exposed to climate-related shocks and the stresses and risks those shocks caused did come up with a way to adapt (Waibel *et al.,* 2018; Pandey *et al.,* 2019). Accordingly, farm households with more experience with adverse climate-related shocks in the past are hypothesized to be more likely to undertake adaptation measures.

3.4.2. Dependent and outcome variables in impact models

This study precedes two-stage frameworks to estimate the impact of climate change adaptation strategies on farm income. In the first stage, a farm household faces the choice of J adaptation practices in response to the adverse effects of climate change. Hence, it is a selection model for climate change adaptation strategies. In this stage, the most common ongoing adaptation practices among farmers in the study area and cited in the literature were considered dependent variables (e.g., Hassan and Nhemachana, 2008; Abayineh and Belay, 2017; Hailemariam *et al.,* 2019). The outcome variables in the second stage are logs of farm income, farm income skewness as a proxy for downside risk exposure, vulnerability coefficient as a measure for vulnerability to food insecurity, and Birr' as a measure of cost of risk measurement.

Dependent variables

Farmers in the study area have implemented various adaptation methods in response to perceived long-term changes in climatic conditions. Through a comprehensive literature analysis (Manandhar *et al.,* 2011; Gentle and Maraseni, 2012; Abayineh and Belay, 2017; Keneilwe and Phatsimo, 2018; Hailemariam *et al.,* 2019; Ademe *et al.,* 2019; Mintewab *et al.,* 2021) and consultations with agricultural development agents in the study sites, a total of four practices were identified. The household survey inquired about the adaptation options that households may have implemented throughout the past decade. Respondent households are classified as adopters if they answered affirmatively, "Have you implemented any adaptation strategies in the last decade?"

Given the primary objective of this study, it is essential to examine the advantages of both individual and joint adoption of adaptation practices. To effectively capture cross-sectoral adaptations and interactions, the study has developed variables. More precisely, the survey has identified six major adaptation types, which can be broadly classified into three groups based on the literature (Wekesa *et al.,* 2018; Mintewab *et al.,* 2021). These groups comprise crop management practices, soil and water conservation measures, and livelihood portfolio diversification strategies.

Crop management practices: Refer to farmers' various activities and techniques to cultivate and care for crops. Some of these practices include using improved crop varieties, drought-tolerant crop varieties, and legumes in crop rotation, changing planting dates with conservation agriculture techniques like minimal tillage, and making good use of inorganic fertilizers, and following exemplary crop management practices. Crop management practices are crucial in climate change adaptation (Wekesa et al., 2018; Zerihun *et al.,* 2018; Mintewab *et al.,* 2021). As the climate continues to change with rising temperatures, changing rainfall patterns, and increased occurrences of extreme weather events, the agricultural sector needs to adapt to these changing conditions. By employing these and other crop management practices, farmers can enhance the resilience and adaptability of agricultural systems to climate change. This, in turn, contributes to food security and sustains agricultural productivity in the face of evolving climatic conditions (Wekesa et al., 2018).

Soil and water conservation measures: Refer to a set of practices and strategies to prevent soil erosion, improve water management, and sustain the health and fertility of agricultural lands. These measures typically include organic manure contour plowing, terracing, cover cropping, mulching, stone walls, and soil bunds on private field plot levels. Several research studies (Tadele *et al.,* 2014; Million *et al.,* 2019) show that conserving soil and water helps keep the soil's fertility and nutrient levels essential for plant growth. This is particularly important in the face of extreme weather events, such as heavy rainfall or more extended drought periods, which are expected to increase with climate change. Million *et al.* (2019) also reported that taking steps to protect soil and water positively affects the amount of money spent on food per person and the net value of crops. It also makes it much less likely for farmers to be food insecure. This includes being at risk of food insecurity as well as being in a state of temporary or long-term food insecurity.

Livelihood portfolio diversification strategies: Refer to engaging in various activities or sources of income to reduce dependence on the agricultural sector. It comprised practices such as non-farm rural wage or petty trades (excluding the sale of natural resources), crafts/small industry, services, rents, food and drink processing, and remittances. Livelihood diversification enables rural households to devise other means to promote their income level and minimize their susceptibility to different livelihood shocks (Baird *et al.,* 2014)

Outcome variables

Farm income: It is the total earnings or revenue from agricultural activities such as crop production, livestock rearing, or other farming operations. It includes the income from selling crops, livestock, dairy products, poultry, and other agricultural products. It is a crucial indicator of the financial performance of a farm or agricultural enterprise and is measured in Birr.

Downside risk exposure: Refers to the potential negative impacts or vulnerabilities arising from unfavorable events, such as climate change and financial shocks (World Economic Forum, 2012). It refers to the degree to which a farmer is exposed to adverse events or uncertainties that can lead to decreased crop yield. It is the risk located in the lower tail of the payoff distribution (Kim *et al.,* 2014). This study calculates farm income skewness using the third central moment, following previous research by Issahaku and Abdulai (2020) and Menale *et al.* (2015).

The process of estimating the moments of crop revenues involves a sequential estimate approach. This procedure begins by regressing the farm income on explanatory variables. The residuals are then obtained from this regression. The calculation of the third moment involves cubing the residual (Di Falco and Chavas 2009). The predicted third moment of farm income is utilized as the result variables. The skewness of crop revenue is considered a valuable measure for assessing farm performance, particularly in climate uncertainty. Skewness is a useful metric as it provides insights into the extent of exposure to potential losses or downside risks (Antle, 2010; Di Falco and Chavas, 2009).

Household food insecurity status: is a binary dependent variable utilized in the model, which is assigned a value of 1 if a household is classified as food insecure and 0 if it is considered food secure. To determine a household's food insecurity status, the total caloric intake is assessed, focusing on the number of kilocalories consumed per adult equivalent each day. This assessment involves comparing the household's daily caloric intake to the established daily minimum requirement of 2200 kilocalories per adult equivalent (kcal/AE/day). Households that meet or exceed this threshold of 2200 kcal/AE/day are classified as food secure, while those falling below this level are categorized as food insecure. This criterion allows for a clear distinction based on nutritional adequacy within the household.

The vulnerability to food insecurity: Refers to the likelihood of a household or individual experiencing food insecurity in the future. It considers factors such as exposure to risks and shocks and the ability to cope with and recover from them. This concept helps identify the causes and consequences of food insecurity and can guide interventions to prevent or reduce it (Scaramozzino, 2006; Christiaensen and Subbarao, 2005). The vulnerability coefficient measures it, and those households with a vulnerability coefficient greater than or equal to 0.5 are vulnerable to food insecurity and, otherwise, if not vulnerable,

Cost of risk: In the context of this study, the cost of risk refers to the financial burden that farmers are willing to bear in order to address the uncertainties and potential losses caused by climate change impacts. This cost is assessed using the Arrow-Pratt risk premium, which represents the monetary value of the risks they face and their willingness to pay to mitigate uncertainties related to climate variability, such as extreme weather events, water scarcity, pests, diseases, and reduced crop yields (Di Falco and Chavas, 2009). As the effectiveness of climate change adaptation strategies improves, the uncertainty and potential losses associated with climate change risks decrease. Consequently, the Arrow–Pratt risk premium may also decrease, indicating a reduced amount that farmers would be willing to pay to mitigate risk Menale *et al.*,2015).

Table 2. Summary of the variables type, definition, measurement and hypothesis for the MVP and impact models.

Variables	Description and Measurement	Variable type	Expected signs
Dependent variable			
Crop diversification	1 if households choose crop diversification, 0 otherwise	Dummy	
Improved crop varieties	1 if households choose improved crop varieties, 0 otherwise	Dummy	
Soil and water conservation measures	1 if households choose soil and water conservation measures, 0 otherwise	Dummy	
Livelihood portfolio diversification	1 if households choose livelihood portfolio diversification, 0 otherwise	Dummy	
Outcome variables			
Farm income	It is the total earnings or revenue from agricultural activities	Continuous	
Downside risk	Farm income skewness	Continuous	
Household food insecurity status	1 if a household is classified as food insecure and 0 if it is considered food secure.	Dummy	
Vulnerability to Food Insecurity	Vulnerable to food insecurity= 1, if VC ≥ 0.5; 0, otherwise	Dummy	
Cost of risk	Financial burden or expenses associated with managing the risks posed by climate change	Continuous	
Treatment Variables			
$A_1S_1L_1$	Farm households adopted all of the practices jointly (yes=1)	Dummy	
$A_0S_1L_1$	If farm households adopted only soil and water conservation and livelihood portfolio diversification (yes=1)	Dummy	

Variables	Description and Measurement	Variable type	Expected signs
$A_0S_0L_1$	If farm households adopted only livelihood portfolio diversification (yes=1)	Dummy	
$A_0S_1L_0$	If farm households adopted only soil and water conservation (yes=1)	Dummy	
$A_0S_0L_0$	If farm households did not adopt any practice, (yes=1)	Dummy	
$A_1S_0L_1$	If farm households adopted only crop management and livelihood portfolio diversification (yes=1)	Dummy	
$A_1S_1L_0$	If farm households adopted only crop management and soil and water conservation, (yes=1)	Dummy	
$A_1S_0L_0$	If farm households adopted only crop management (yes=1)	Dummy	
Independent variables			
GENDER	1, if the household head is male; 0, otherwise	Dummy,	+VE
AGEHH	Age of household head in years	Continuous	±VE
EDUCHH	Education level of the household head = 0 if illiterate; 1 if grade 1–8; 2 if grade 9–12; 3 if above grade 12	Categorical	+VE
FAM_SIZE	The total number of household size	Continuous	+VE
LIVESTOCK	Livestock holding in tropical livestock unit (TLU)	Continuous	+VE
FARM_SIZE	The total cultivated land owned by the household in a hectare	Continuous	+VE
CREDIT	1, if the household has access to credit; 0, otherwise	Dummy	+VE
DIST_MKT	The distance between the market and the respondent's house in walking hours	Continuous	-VE
EXTE	Frequency of extension contact 1, if ≥ 6; 0, otherwise	Dummy	+VE
MSEG	Membership in local institutions 1, if > 2; 0, otherwise	Dummy	+VE
CLMT_INF	1, if HHH has access to climate information; 0, otherwise	Dummy	+VE
GOOD SOIL	1, if good soil quality plot; 0 poor soil quality	Dummy	-VE
MODERATE SOIL	1, if medium soil quality plot; 0 poor soil quality	Dummy	-VE
SLOPE FLAT	1, if flat slope plot; 0 steep slope	Dummy	-VE
MODERATE SLOPE	1, if medium slope plot; steep slope	Dummy	-VE

Variables	Description and Measurement	Variable type	Expected signs
EROSION	1 if farmland has portions of moderate to severe erosion intensity and 0 otherwise	Dummy	+VE
CLMT_SHOCK	If the farm household experienced any climate related shock in the last 5 years	Dummy	+VE
CLMT_PERC	Climate change perception (mean 5-point Likert-scale)	Continuous	+VE

4. RESULTS AND DISCUSSION

This chapter is divided into two sections. The first section discusses the socio-demographic characteristics of respondents using descriptive statistics. It also examines farmers' perceptions of changes in climatic parameters, climate related shock experiences, and the adaptation strategies employed to reduce the adverse effects of climate change. The second section uses an econometric application to examine the factors that influence smallholder farmers' decisions to adopt climate change adaptation strategies. Additionally, it presents the results of estimating the impacts of adopting these strategies on farm income, downside risk, vulnerability to food insecurity, and the cost of risk.

4.1. Descriptive Statistics

The sampled farmers' demographic and socioeconomic data were analyzed using descriptive tools such as mean, percentage, standard deviation, and frequency distribution**.** Additionally, their perceptions of climate change, its impacts on agriculture**,** and the adaptation practices they had been implementing on their farmland were studied. The most frequent climate-related shocks experienced by them were also examined. Furthermore, *t*-test and χ^2-test statistics were used to compare those who do not adapt for some explanatory variables. Moreover, the five-point Likert scale elicited information on the respondent's perceptions of climate change and climate-induced hazards. Together, the Likert scale and the descriptive analysis of the household survey data addressed research question number one.

4.1.1. Socio-Demographic Characteristics of the Sample Households

Table 3 indicates the characteristics of sample households related to several categorical variables. Males were still found to be dominant in the adaptation strategies of climate change. As shown, 78% of sample adopters are male-headed, while the rest, 22%, are female-headed households. Out of the 86 female-headed households, 79 (91.86%) were adopters, and 7(8.14%) were nonadopters.

Respondents were asked to state their highest educational attainment to assess the influence of education on adapting to climate change. The result indicates that more than one-third of the total sample (38 percent) had yet to attain any level of schooling. Nearly half of the entire sample (48 percent) achieved a primary level of education, and those who attained senior secondary education represent around a semi-quarter of the sample respondents. Moreover, of the total sample of respondents, 36.08 percent of adopters and 57.89 percent of nonadopters were no formal education, which also showed a significant mean difference at a 5% level.

Improving access to finance, especially access to credit by providing small loans, is considered necessary to minimize the adverse effects of climate change and variability since it contributes to strengthening the smallholder's productive assets. The result shows that 50.77% of the sampled households had no access to credit services. A significant proportion of adopters (50.57 percent) and nonadopters (52.63 percent) reported that they had not accessed any credit service, with no significant association (χ^2=0.809) between the two groups.

The frequency of contact with the extension agents was also considered. In this regard, out of the total sampled respondent, 42.05 percent of farmers had no contact with extension service agents at least six times a year. The rest, 57.95 percent, had gotten technical advice and support at least six times a year. The number of respondents who contact extension service agents at least six times per year in the adopter group was 59.38 percent, while in the non-adopters' group, the number was 40.63 percent. The results of Chi-square tests show significant variation in the frequency of contact with the extension agents between the two groups.

Participation in socioeconomic groups is anticipated to increase climate change awareness due to sharing information between farmers at their occasional meetings. It is used as a proxy for social capital endowment. In this aspect, 40 percent of the respondents from the total sample participated in or belonged to at least two socioeconomic groups. Surprisingly, there was no difference in group membership between the adopters and nonadopter farmers. Among the adopters, 39.5 percent had a member of at least two socioeconomic groups, and 60.5 percent had no such membership; at the same time, 40 percent of nonadopters were also members of at least two groups. The Chi-square result reveals that the difference in membership in a socioeconomic group is not statistically significant between adopters and nonadopters of adaptation options.

The respondents were also asked if they could access climate change early warning and related information. As a result, 34.1 percent of households receive early warning information. In contrast, a substantial proportion (65.9 percent) of households did not receive early warning information that would have helped reduce the adverse effects of climate change and variability through preparedness. There was no significant difference in mean between the two groups.

Smallholder farmers' adoption decision of soil fertility management and soil conservation practices is heavily influenced by physical plot characteristics, such as slope, soil depth, level of soil fertility, and prospective productivity. In this regard, 47.18 percent and 34.10 percent of the total respondents perceived their farm was good and moderately fertile, respectively. Moreover, 47.37 percent of nonadopters and 32.67 percent of adopters perceived their farms as good and moderately fertile, respectively.

The study also gathered information on household perceptions about their farm plot. Of the total sample, 47.44 percent and 30.51 percent perceived their farm plot as flat plot slopes and moderately sloped plot, respectively. Among the adopters, 48.3 percent perceived their farm plot as a flat slope, whereas 29.26 percent perceived it as a moderately sloped plot. On the other hand, the number of respondents who perceived their plots as having a flat slope and a moderate plot slope in the non-adopters' group was 39.47 percent and 42.11 percent, respectively. The chi-square analysis reveals that farmers' perception of flat plot slopes and moderately sloped plot slopes between adopters and nonadopters was found to be not significant.

The respondents were also questioned regarding their perception of the severity of soil erosion. Among the total respondents, 48.72 percent of sample farmers regarded their plots as severely eroded, whereas the rest, 51.28 percent not perceived. About 51.14 percent of adopters and 26.32 percent of nonadopters perceived their farms as severely eroded, while about 48 percent of adopters and 74 percent did not perceive their plots as severely eroded. The chi-square test result revealed a difference in perception of the severity of soil erosion between adopters and nonadopters farmers at a 5 percent significance level (Table 3).

The perceptions of farmers towards risks, for example, drought, crop failure, climate change, and other shocks, are also considered. Around 34.38% and 67.79 % of adopters and nonadopters, respectively, were perceived as having a low impact on climate change; 47.44% of adopters and 26.32% of nonadopters were found to have perceived a medium impact. In comparison, 18.18% of adopters and 7.89% of nonadopters were found to have perceived the high impact of climate change. The mean difference was statistically significant at a 1% level.

Table 3. Characteristics of sample households: categorical variables.

Variables	Description	Adopters		Non-adopters		Chi-square test (χ2)
		Number	%	Number	%	
Gender	Male	273	77.6	31	81.6	0.32
	Female	79	22.4	7	18.4	
Level of Education	No formal Education	127	36.1	22	57.9	7.54**
	Primary	174	49.4	14	36.8	
	Secondary	51	14.5	2	5.3	
Access to Credit	Yes	174	49.4	18	47.4	0.06
	No	178	50.6	20	52.6	
Extension Contact	>=6	209	59.4	17	44.7	3.02*
	<6	143	40.6	21	55.3	
Membership	>2	139	39.5	15	39.5	0.001
	<2	213	60.5	23	60.5	
Climate Information	Yes	116	33	17	44.7	2.12
	No	236	67	21	55.3	
Good soil	Yes	168	47.7	16	42.1	0.44
	No	184	52.3	22	57.9	
Moderately fertile soil	Yes	115	32.7	18	47.4	3.29*
	No	237	67.3	20	52.6	
Flat plot slope	Yes	170	48.3	15	39.5	1.07
	No	182	51.7	23	60.5	
Moderately plot Slope	Yes	103	29.3	16	42.1	2.67
	No	249	70.7	22	57.9	
Severity of soil erosion	High	180	51	10	26.3	8.46**
	Low	172	48.9	28	73.7	
Perceived climate shock	Low	121	34.4	25	65.8	14.53***
	Medium	167	44.4	10	26.3	
	High	64	18.2	3	7.9	

Source: Own computation from household survey (2022). ***, **, and * indicates statistical significance at less than 1%, 5%, and 10%, respectively.

Tables 4 present the continuous explanatory variables expected to influence smallholder farmers' adoption of adaptation options in response to the adverse effects of climate variability and change. As shown in Table 4, respondents' ages were noted as distinct numerical values.

However, the analysis was organized to facilitate concise comprehension and presentation. The minimum and maximum ages obtained from the results are 21 and 71, respectively, while the mean age is 42. The average age of the adopters is older than that of the non-adopters, and the difference is statistically insignificant. In addition, general observation reveals that approximately 96 % of all respondents were between the ages of 21 and 64. This indicates that most of the respondents are in the economically productive age group. Furthermore, a small percentage of respondents (approximately 4 percent) are 65 or older.

Family labor is recognized as a significant source of labor for adopting labor-intensive productivity-enhancing practices in most of Ethiopia, including the study area. This includes the mental and physical efforts of all males, females, and children in a household who contribute to the upkeep of the household's assets. As depicted in Table 4, the sample population has a mean family size of 4.7, with a standard deviation 2.08. This family size almost equals the national average of 4.6 people per household (CSA, 2007). In addition, the average family size of non-adopters and adopters of adaptation strategies is 4.6 and 4.7, respectively. The mean comparison test revealed that adopters and non-adopters do not differ significantly regarding family size.

Substantial reliance on livestock ownership characterizes smallholder agriculture in the studied area. Livestock provides draft power (tillage, threshing, and transportation) and generates cash to purchase agricultural inputs (such as inorganic fertilizer) and other expenses. The average number of animals owned by sample households, as measured in Tropical Livestock Units, is 3.5. The average number of animals owned by non-adopters and adopters of climate change adaptation strategies is 1.92 and 3.71, respectively. The mean difference in livestock ownership between adopters and non-adopters is statistically significant (less than 1 percent). It suggests that households with more livestock are more likely to adopt adaptation strategies than those with fewer animals.

The land is a major agricultural productive asset and wealth indicator. The average farm size of sample households in the study area is 1.42 hectares of own farmland, with an average size of 1.28 and 1.44 hectares for non-adopters' and adopters' households, respectively. Although the differences in own farmland between the two categories are not significant, it is observed that the average land holdings of sample households are greater than the national average landholdings, which is less than 1 hectare (Rapsomanikis, 2015).

Distance from a household's residence to the input-output market also has a vital role in farming decisions to implement strategies in response to climate change. The average walking distance from the household's home to the marketplace is 32 minutes. On average, adopters need to travel just 31.51 minutes to access the nearest input-output market, while that of non-adopters is 31.36 minutes. The results of the statistical analysis reveal no significant difference between adopters and non-adopters of the adaptation option in terms of the average walking distance of sample residences.

Perception of climate change is essential to raise farmers' awareness about the changes in local climatic conditions. Therefore, farmers can consider applying climate change adaptation strategies to their farmlands. The mean perception value for the pooled sample is 1.01, with an average value of 0.86 and 1.02 for non-adopters and adopters of adaptation strategies for climate change. Results show a significant difference between adopter and non-adopter households at a 1% significance level regarding the perceived impacts of changing climate.

Table 4. Characteristics of sample households: continuous variables

Variables	Mean	Adopters	Non-adopters	t-value
Age	42.5 (0.56)	42.6 (0.59)	41.8 (1.74)	-0.39
Family Size	4.7 (0.11)	4.7 (0.11)	4.6 (0.3)	-0.43
Livestock	3.5 (0.16)	3.7 (0.17)	1.9 (0.2)	-6.56***
Farm Size	1.4 (0.04)	1.4 (0.04)	1.3 (0.12)	-1.22
Distance to market	31.5 (1.14)	31.5 (3.85)	31.4 (1.19)	0.04
Climate perception	1.01 (0.02)	1.02 (0.02)	0.86 (0.06)	2.72***

Source: Own computation from household survey (2022). *** indicates statistical significance at less than 1%. Numbers in parenthesis are standard errors.

Table 5 displays the distribution of farm income among two categories of households: those who have adopted climate change adaptation strategies and those who have not. The table reveals a noteworthy contrast in average farm income, with adopters reporting a mean income of Birr 31,279.2, compared to Birr 18,080.0 for non-adopters. This substantial difference of Birr 13,199.2 indicates that households implementing adaptation strategies experience significantly higher economic outcomes. Furthermore, the standard deviation of income for non-adopters is higher (Birr 1,341.8) than for adopters (Birr 582.2), suggesting a wider variability in income levels among non-adopters. The t value of 9.02 further confirms the statistical significance of this difference in mean income, providing compelling evidence that adopting these strategies leads to improved financial performance. These findings highlight the possible benefits of climate change adaptation techniques for improving smallholder farmers' livelihoods, as well as the significance of disseminating these measures to non-adopter households to increase economic resilience.

Table 5. Descriptive summary of farm income

Variable	Sample Households Mean	Adopters Mean	Non-Adopters Mean	Difference in Mean	t value
Farm income	29,993.2 (576.3)	31,279.2 (582.2)	18,080.0 (1341.8)	13,199.2 (1462.3)	9.02***

Source: Own computation from household survey (2022). *** indicates statistical significance at less than 1%. Numbers in parenthesis are standard errors.

4.1.2. Farmers' Perceptions of Climate Change and Variability

Smallholder farmers employ various technical measures to reduce the adverse impacts of climate change and variation. However, the extent of farmers' awareness and perceptions of climate change influences these strategies and, consequently, their level of adaptation. In this aspect, the respondents were asked to rank their perception of climate change and variability in terms of rainfall distribution, perception of temperature variability, and climate-induced hazards in terms of a decrease or an increase using a five-point Likert scale (-2, 2), where 0 = no change, +1 = increase, −1 = decrease, +2 = high increase and −2 = high decrease.

4.1.2.1. Farmers' perceptions of rainfall variability

Implementing local adaptation strategies to climate change depends on how local people perceive the changes in climatic conditions. Figure 3 shows the households' perception of climate change and variability in rainfall distribution, amounts, and duration over the last ten years. An overwhelming majority of farmers have observed a decline in rainfall quantity (86.9%) and duration (80.8%) over the last decade. Additionally, 90.8% reported increased unpredictability in the timing of the rainy season's onset and end. Overall, the majority of farmers in the study area have observed significant changes in rainfall patterns over the past decade.

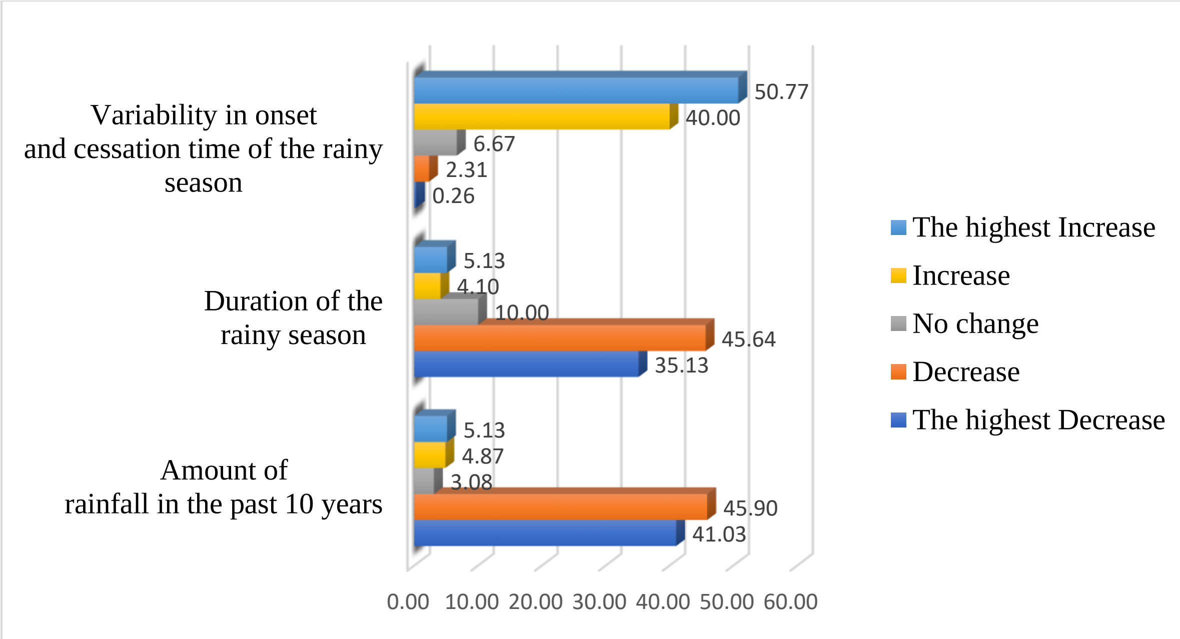

Figure 3. Farmers' Perceptions of Rainfall Variability.
Source: Own computation from household survey (2022).

The information from the key informant interview aligns with the documented decrease in the amount of rainfall and the increased unpredictability of the rainy season. The informant mentioned, "I have noticed a reduction in the quantity of rainfall, along with shorter rainy seasons. The rainfall doesn't persist for as long as it did before, and the timing of the rainy season's onset and conclusion has become much more uncertain." These direct testimonies from farmers add weight to the descriptive results, which revealed that 86.9% of participants observed longer periods of dry weather and a less dependable rainy season. This highlights the importance of implementing local adaptation strategies to climate change based on the perceptions and experiences of local people.

4.1.2.2. Farmers' perception of temperature variability

Respondents were also asked to identify some of the variabilities they have observed in the environment resulting from temperature variations over the past ten years. Figure 4 shows farmers' perception of temperature variability regarding the mean temperature, dry season period, and warm nights. The figure reveals a clear pattern of perceived temperature increases and extreme weather variability as reported by the farmers. As indicated, the vast majority of respondents (84.1%) have observed a rise in average temperatures over the past decade. Moreover, a significant proportion have noted concerning changes in other temperature-related indicators, such as longer dry seasons (86.9%), more frequent hot days (84.6%), and a greater number of warm nights (90.3%) per year.

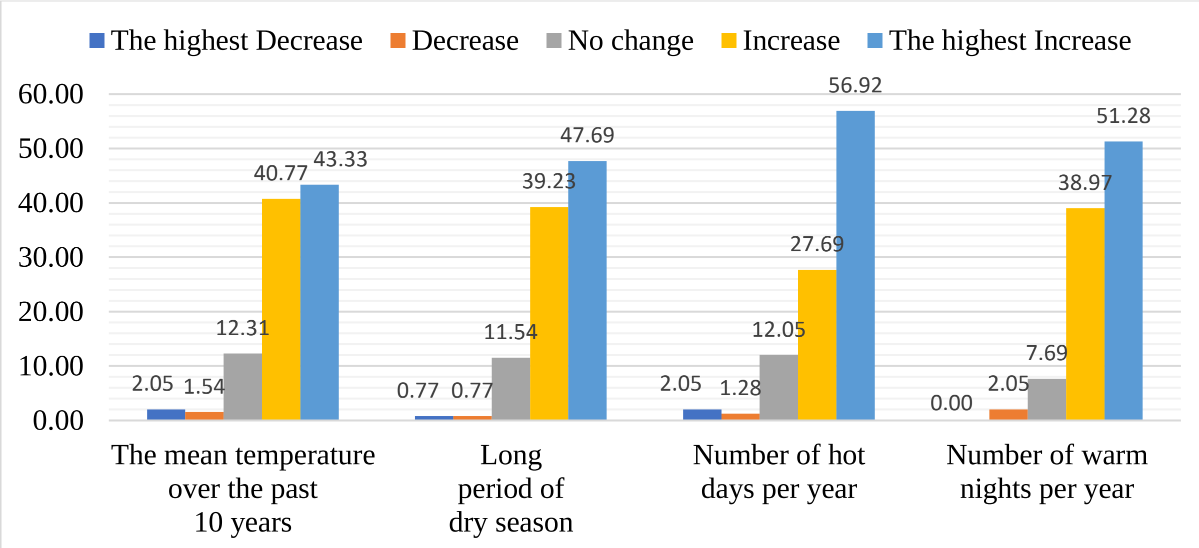

Figure 4. Farmers' Perception of Temperature Variability.
Source: Own computation from household survey (2022).

The key informant interviews conducted as part of this research offer important firsthand insights into the climate changes experienced by local farmers over the past 10-20 years. These qualitative findings provide crucial context and depth to the quantitative trends observed in the descriptive analysis. A primary theme that emerged from the interviews was the notable increase in nighttime temperatures reported by the farmers. As one informant described, "One of the most noticeable changes has been an increase in the hotness during the nighttime. The temperatures seem to be higher at night compared to what I remember from earlier in my farming career." This aligns with the descriptive analysis, which found that a significant majority of respondents (90.3%) perceived an increase in the number of warm nights per year.

These observed shifts in temperature and weather patterns are deeply concerning, as they are likely to have far-reaching impacts on agricultural productivity, livestock health, and the broader environmental conditions in the study area. The temperature-driven changes may contribute to increased water scarcity, crop failures, livestock deaths, and environmental degradation - posing substantial challenges for the local farming communities whose livelihoods depend on the land.

4.1.2.3. Farmers' perceptions of climate shocks

Table 6 present the type of shocks perceived by household in the last two decades. The shocks were refined during the pre-test of the survey. Households reported the seven most critical adverse shocks to have increased over the past years. Nearly 56 percent and 55 percent of respondents experienced flooding and landslides, and death of livestock, respectively. Almost 47 percent of respondents noted increased infestation of crop diseases and insects. On the other hand, about 42 percent and 52 percent of the respondents perceived the introduction of more weeds and the drying up of streams. Most respondents experienced crop yield decline (56 percent) and flooding and landslides on the farm (55 percent). A total of 41.5 percent of respondents perceived degradation of their soil in recent years due to the impact of climate-related changes.

The key informant shared valuable insights on how the observed climate changes have directly affected their farming operations and productivity. They described the significant challenges posed by the evolving climate conditions, stating, "The observed changes in climate have profoundly impacted my farming activities and overall productivity over the past decade. One of the most pressing issues has been the increased infestations of pests and plant diseases, likely resulting from fluctuating temperature and humidity levels. These threats have led to greater crop losses, reducing our overall productivity and food security. Maintaining consistent, high-yielding harvests has become incredibly challenging due to these climate-related obstacles. Consequently, our total production has declined significantly over the past 10-15 years, compelling us to increasingly rely on food aid and tubers to meet our basic needs. The struggle to sustain our livelihoods persists, and I am concerned about our ability to do so if these trends continue."

Table 6. Type of perceived climate shocks by household

Impacts	% of respondents				
	The highest decrease	Decrease	No change	Increase	The highest increase
Flooding and landslides	0.8	1.8	7.7	34.1	55.6
Death of livestock and destocking	0.0	1.5	11.5	32.3	54.6
Increase infestation of crop diseases and insects	0.3	0.5	10.8	41.0	47.4
Introduction of more weeds	0.3	1.8	15.1	40.3	42.6
Drying up of streams	0.8	1.3	15.4	30.5	52.1
Crops yield decline	0.8	0.0	12.6	30.5	56.2
Land degradation	2.6	0.5	15.4	40.0	41.5

Source: Own computation from household survey (2022).

Additional data on the extent of risks to the shocks was collected from the households that encountered them. Respondents were required to categorize the impacts as low, medium, or high in order to determine the severity of the climate-induced shocks. The severity levels are categorized based on the extent of harm caused to the household. A low severity level indicates that no major harm was done, while a medium severity level suggests that manageable damage occurred. On the other hand, a high severity level signifies the occurrence of events that resulted in the loss of land or posed a threat to life.

Table 7 provides severity of the risks to climate-related shocks perceived by households. The highest proportion of households perceived medium severity of risks to the shocks for the death of livestock and destocking (48%), increased infestation of crop diseases and insects (55%), introduction of invasive species or more weeds (48%), and crop yield decline (51%). Notably, the most commonly reported shock earlier was land degradation, with 19% of the respondents having experienced it; however, their perceived risks are low. Moreover, Table 7 shows that over 30% of respondents reported high severity of the risks for crop yield decline and 20% for increased infestation of crop diseases and insects.

This implies that climate-related changes have a significant and negative impact on the agricultural production and productivity of the respondents. These effects have worsened the livelihoods and food security of the respondents, as well as the environmental sustainability of their farming practices. It is also suggested that the respondents need more adaptation and mitigation strategies to cope with the climate-related changes and reduce their vulnerability.

Table 7. Severity of the risks to shocks perceived by households

	Severity of Risks					
	Low		Medium		High	
Shocks	Number	%	Number	%	Number	%
Flooding and landslides	29	52	18	32	9	16
Death of livestock and destocking	18	38	23	48	7	15
Increase infestation of crop diseases and insects	12	24	27	55	10	20
Introduction of more weeds	20	32	30	48	12	19
Drying up of streams	23	46	21	42	6	12
Crops yield decline	9	18	25	51	15	31
Land degradation	35	46	33	43	8	11

Source: Own computation from household survey (2022).

4.1.3. Actual Variability and Trends of Temperature and Rainfall

4.1.3.1. Variability of temperature

The mean annual temperature data is determined by taking the average of the maximum and minimum temperatures. The mean and standard deviation values of temperature during the study period of analysis are presented in Table 8. The average annual minimum and maximum temperatures observed from 1989 to 2021 were recorded as 14.4 °C and 27.7 °C, with a standard deviation of 1.2 and 1.7, respectively. The Table also provide insights into the temperature variations within specific seasons in the study area. For example, the Belg season tends to have higher maximum temperatures but also greater temperature variability compared to the Kiremt and Bega seasons.

Table 8. Mean maximum, minimum, and annual temperatures (°C) in study area in 1989–2018

	Maximum Temperature		Minimum Temperature	
Annual and seasonal	Mean	Standard Deviation	Mean	Standard Deviation
Annual	27.7	1.2	14.4	1.7
Belg	23.9	9.8	12.2	5.2
Kiremt	20.3	9.4	11.7	5.5
Bega	22.9	8.5	10.9	4.3

Source: Computed based on data obtained from NMSA, Aman Station.

Figure 5 illustrates the year-to-year variation of the annual mean temperature expressed as temperature deviations from the long-term average (1989–2021). As can be seen from the figure, it was cooler than average from 1989 to 2021 and relatively warmer from 2002 to 2021. Figure 5 also reveals the warming trend in the mean annual temperature over the past 25 years. The regression lines show it has increased by about 1.1 C every ten years.

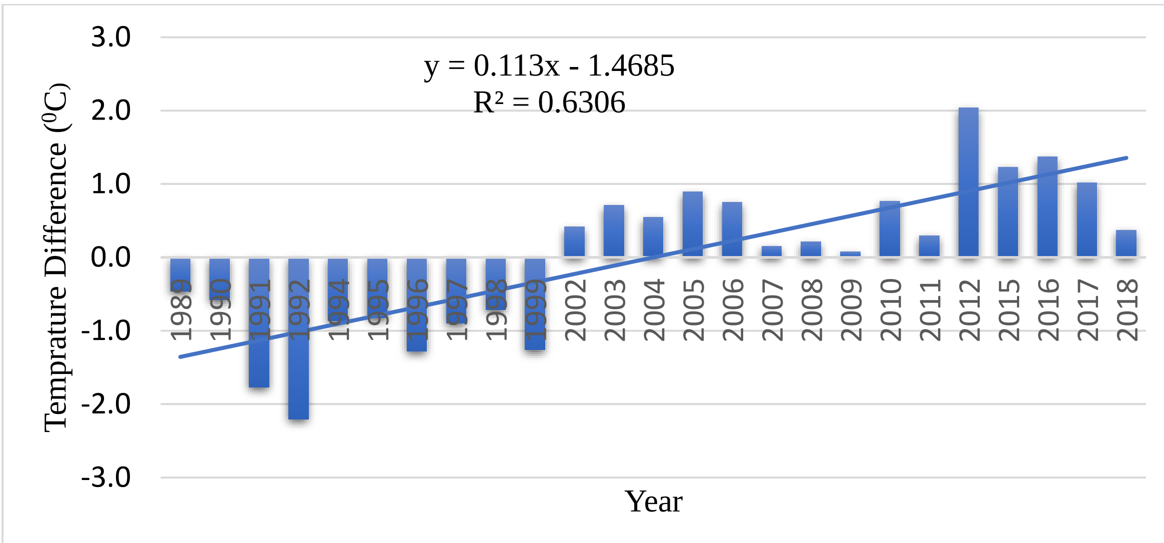

Figure 5. Mean annual temperature departure from normal with during 1989 – 2018
Source: Computed based on data obtained from NMSA, Aman Station.

The results of the Mann-Kendall test of annual maximum temperature during the period 1989–2018 are given in Table 9. The Table shows that the annual mean temperature shows a statistically significant positive trend at a 5% significance level. This trend is in harmony with farmers' perceptions, where most farmers believed in increased hot days and warm nights in their vicinities. Previous works (Hailay *et al.,* 2019; Moroda *et al.,* 2018) also support this congruence between farmers' perceptions of an increased temperature trend and meteorological results.

Table 9. Annual maximum temperature trend analysis

Maximum Temperature (^{0}C)				Minimum Temperature (^{0}C)			
Kendall's tau	S	P- value	Sen's slope	Kendall's tau	S	P- value	Sen's slope
0.484	92.00	0.003**	0.074	0.168	32	0.315	0.034

Source: Computed based on data obtained from NMSA, Aman Station.

4.1.3.2. Variability of rainfall

Ethiopian agriculture is characterized by two prominent agricultural production seasons: the "Meher" (or main) and "Belg" (short rain) seasons. The Meher season is commonly defined as an extended period of precipitation, typically spanning from June to September. The term "Belg season" often denotes the short yet timely rainy season, typically observed between February and May, but in specific regions of the country (Ahmed, 2011).

Rainfall amounts and distribution are crucial for rain-fed agriculture in the study area. Results of the applied Mann-Kendall and Sen's slope estimator statistical tests for seasonal and annual rainfall over the period 1982–2018 are presented in Table 10. The values of rainfall were aggregated to obtain seasonal and annual rainfall.

Kendall's tau of 0.083 suggests a weak positive trend in annual rainfall over the analyzed period, indicating a slight increase over time. However, the p-value of 0.56, which is higher than the commonly used significance level of 0.05, implies that the trend is not statistically significant. The Sen's slope of 11.5 mm/year further supports the small positive trend in annual rainfall. The Belg season rainfall trend exhibits a weak positive trend, with a Kendall's tau of 0.114. The p-value of 0.427 suggests that the trend is not statistically significant. The Sen's slope of 5.125 mm/year, which indicates a slight increase in Belg season rainfall over the analyzed period, further supports this observation.

Interestingly, the Kiremt season exhibits a negative correlation (Kendall's tau = -0.066). The p-value of 0.66 is higher than the significance level, indicating that the trend is not statistically significant. The Sen's slope of -3.567 mm/year suggests that Kiremt season rainfall tends to decrease over the analyzed period. While the analysis of annual and seasonal rainfall trends does show some interesting patterns, such as a weak positive trend in annual and Belg season rainfall and a small negative trend in the Kiremt season, these trends are not statistically significant. This underscores the need for further research and monitoring to gain a better understanding of and predict future rainfall trends in the study area, a task of utmost importance.

Table 10. Annual and seasonal rainfall trend analysis

Annual				Belg				Kiremt			
Kendall's tau	S	P-value	Sen's slope	Kendall's tau	S	P-value	Sen's slope	Kendall's tau	S	P-value	Sen's slope
0.083	27	0.56	11.5	0.114	37	0.427	5.125	-0.066	-21	0.66	-3.567

Source: Computed based on data obtained from NMSA, Aman Station.

Figure 6 reveals there is immense season-to-season variability of rainfall totals (<150 mm to >2000 mm) with a mean of 1561 and a standard deviation of 656 mm (CV of 42%). Regression lines were fitted to check for evidence of trends in rainfall totals, but no statistically significant trend was extracted from the rainfall data. The actual meteorological data align with the perceptions of climate change and variability held by farmers, which indicate a decline in the mean seasonal rainfall.

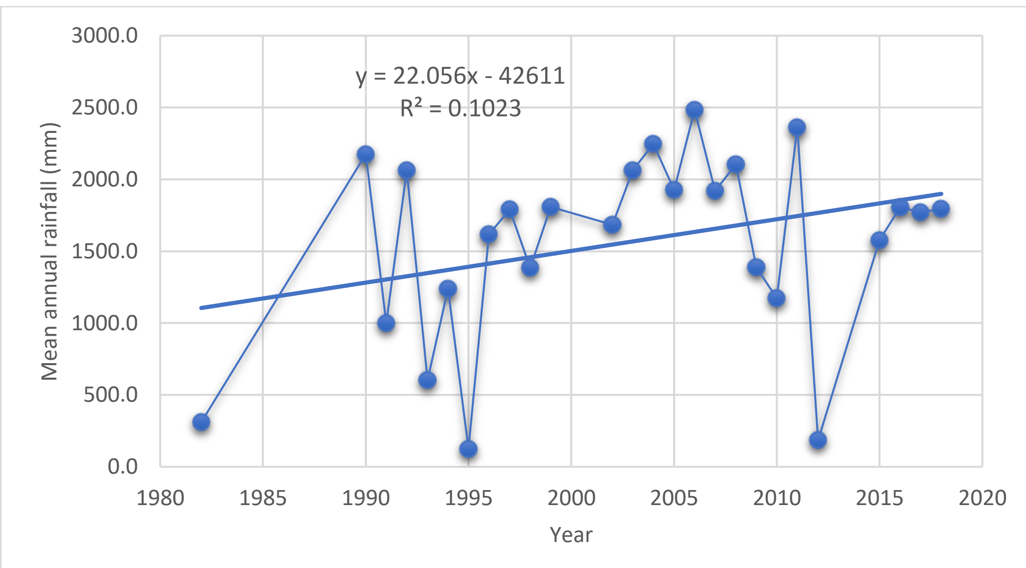

Figure 6. Total annual rainfall during 1982–2020
Source: Computed based on data obtained from NMSA, Aman Station

The observed upward trend in temperature and concurrent decrease in rainfall during the rainy season have had adverse consequences on the livelihoods of smallholder farmers in the study area since their livelihoods are contingent upon the presence of adequate precipitation and suitable temperatures.

4.1.4. Farmers' adaptation strategies to climate change

As mentioned in the previous section, most farmers are aware of climate change and its effects on crops, livestock, water, the environment, and their livelihoods. Due to climate change and variability, the adverse consequences will worsen unless action is taken (Singh *et al.,* 2014; Aemiro *et al.,* 2012). Hence, in response to long-term anticipated changes in climatic situations, smallholder farmers in the studied area have implemented several adaptation strategies. In line with this, respondent households are identified as adopters if they answered "yes" to "Have you tried any adaptation strategies within the past decade?" A total of 5 practices were identified through a literature review (Manandhar *et al.,* 2011; Abayineh and Belay, 2017; Keneilwe and Phatsimo, 2018; Hailemariam *et al.,* 2019; Ademe *et al.,* 2019; Mintewab *et al.,* 2021)) and distinguished during the pre-test of the survey in the study sites.

Figure 7 clearly reveals that about 52.1% of farmers have used crop diversification to overcome the adverse impact of climate change in the area. In the study area, crop diversification is widespread. This activity often has a dual purpose. On the one hand, if one variety fails, farmers may still have some other successful crop varieties. Conversely, with rotating crop varieties on each plot of land, soil fertility and the soil will be maintained.

Subsequently, about 44.4% of the farmers have implemented soil and water conservation practices as an adaptation strategy. The study area exhibits topographical features consisting of mountains, with a scarcity of flat terrain suitable for crop cultivation. It necessitates an increased emphasis on soil and water conservation practices to mitigate the potential for soil erosion and precipitation loss. Terraces are often built with soil bunds, stone bunds, and deep trenches. As mentioned above, these strategies are widely employed for soil and water conservation in the field. Million *et al.* (2019) also found that the implementation of soil and water conservation methods has a substantial impact on reducing farmers' susceptibility to food insecurity.

Crop production and animal husbandry are the primary sources of income for smallholder producers in the area. However, both are highly susceptible to climate change. For this reason, 38.2% of farmers have chosen to diversify their sources of income to wage labor and the collection of permanent trees from communal and protected areas for sale as firewood, charcoal, housing, and construction materials. Diversification of livelihoods enables smallholder farmers to devise alternative ways to increase their income and reduce their susceptibility to various livelihood disruptions. Abayineh and Belay (2017) report that in response to the adverse effects of climate variability and change, smallholder farmers have been diversifying their sources of income with the knowledge that more diversified livelihood strategies allow them to increase their incomes and spread their risk.

In response to the observed climate changes in the local area, the key informant outlined several adaptation strategies that smallholder farmers and local governments have embraced. Given the impacts of climate change and variability on agriculture in the study area, these measures are designed to address the challenges posed by extreme weather events. The key informant explained that the adaptation strategies encompass a variety of soil and water conservation methods, such as the construction of stone bunds, soil bunds, and terraces. These physical structures play a crucial role in retaining moisture, reducing soil erosion, and enhancing overall soil and water management on the farms.

In addition to these land management practices, the informant noted that farmers have also adopted various crop management techniques. This includes crop diversification, where multiple crop species are cultivated together, as well as the use of drought-resistant crop varieties that can better withstand periods of low rainfall and high temperatures. Furthermore, the informant emphasized that farmers have diversified their livelihoods beyond relying solely on crop production. This diversification involves engaging in on-farm, non-farm, and off-farm income-generating activities to spread risk and fortify resilience in the face of climate-related challenges.

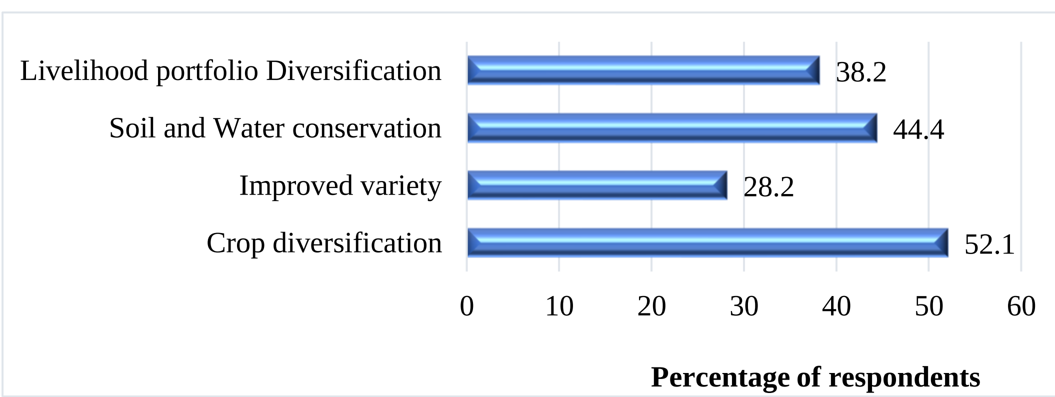

Figure 7. Adaptation strategies used by the farmers in the study area.

Source: Own survey results, 2022.

In conclusion, smallholder farmers in the studied area have implemented various adaptation strategies to cope with climate change. Farmers use different methods to improve their crop yields and support their livelihoods. The most common methods include, crop diversification, soil and water conservation practices, diversification of income sources, and improved crop varieties are also commonly used. By using these methods, farmers can create a sustainable and resilient agricultural system that supports their families and communities for generations to come. These strategies, proven effective, aim to mitigate the adverse effects of climate change, increase income, and reduce vulnerability to climate-related disruptions. Overall, farmers are taking proactive measures to adapt to changing climatic conditions and protect their livelihoods, demonstrating their ability to manage the challenges posed by climate change effectively.

4.1.5. Level of Vulnerability to Food Insecurity in the Study Area

Before determining the level of vulnerability to food insecurity, it is crucial to revisit the determination of the food poverty line. The methodology employed to establish the food poverty line follows a meticulous and systematic approach. Initially, a 'basket' of food items commonly consumed by impoverished households was identified using a comprehensive food consumption questionnaire. The quantity of items in this basket was carefully determined to align with the minimum daily dietary requirement, set at 2,200 kilocalories per adult equivalent. Subsequently, the 'basket' was evaluated based on local costs, leading to the computation of the food poverty line. For the research area, this threshold was identified as ETB 45,359.7.

As a proactive measure to account for inflation, this study utilized consumer price indices from the Central Statistical Agency (CSA, 2023) to adjust the food poverty line at both the country and regional levels. Specifically, the Consumer Price Index (CPI) for the study area (SNNPR) was 382.2% relative to the base year of December 2016. This adjustment was crucial to maintain the accuracy and relevance of the poverty threshold over time. By the end of 2022, the revised food poverty threshold stood at Birr 11,868.05 per adult equivalent per year (at constant prices). A household was categorized as food insecure if its per capita food consumption expenditure (PCFCE) fell below this poverty limit; otherwise, it was considered food secure.

Concerning vulnerability to food insecurity, the rural households in the study areas were categorized as vulnerable or non-vulnerable based on their vulnerability score of < 0.5 or ≥ 0.5, respectively (Pritchett *et al.,* 2000). In addition, the household's current food insecurity status was assessed using the food poverty line. A household is classified as food insecure when the consumption per adult equivalence falls below the threshold level. Conversely, if the consumption per adult equivalence is above the threshold level, the household is considered food secure.

Table 11 presents the distribution of sample households based on their vulnerability to food insecurity and food security status within the study area. The findings shed light on the intricate relationship between climate change adoption and household resilience. The average vulnerability to food insecurity across the study areas stands at 65.3 percent. Notably, a significant proportion of households that actively embrace climate change adaptation measures exhibit lower susceptibility to food insecurity. This encouraging finding suggests that most adopters have successfully implemented strategies to lessen their vulnerability.

However, it's essential to recognize that a substantial segment of climate change adopters (34 percent) remains vulnerable. Despite their efforts to address climate-related challenges, these households continue to grapple with the threat of food insecurity. The paradox lies in the fact that even among those who embrace climate change adaptation, complete protection from its adverse effects still needs to be discovered. Underlying factors or constraints may contribute to this vulnerability, necessitating further investigation. It is evident that among the 196 currently food-secured households, a significant majority, which accounts for approximately two-thirds of the households, exhibited a high level of food security and were deemed unlikely to experience food insecurity in the near future (lower VFI). This is a positive sign, suggesting that these households have reliable access to sufficient and nutritious food, reducing the risk of food insecurity and its associated negative impacts on their well-being. However, it is crucial to note that approximately 25% of the food-secured households (47 out of 196) were identified as facing vulnerability to food insecurity. This is a concerning trend, indicating that despite their current food security status, these households are more likely to experience food insecurity in the future. They may have limited or unstable access to food resources, putting them at a higher risk of insufficient food intake or poor dietary quality.

Shifting our focus to the households currently grappling with food insecurity, out of the 194 surveyed in the study areas, a significant proportion, roughly 52.6% (102 households), were found to be resilient. This resilience, despite their current food insecurity, is attributed to specific characteristics or resources that enable them to mitigate the full extent of food insecurity. It could be due to support from social networks, access to alternative food sources, or other factors that assist them in maintaining a certain level of food security in challenging circumstances.

Table 11. Household classification and decomposition by vulnerability and food security status.

Level of Vulnerability	Food security status				χ^2	Adoption Status	
	Food Insecure		Food Secure				
	No.	%	No.	%		Adopters (%)	Non-adopters (%)
Vulnerable	92	65.3	49	34.8		34.1	55.3
Not vulnerable	102	40.9	147	59.1	21.236***	65.9	44.7
Total	194	49.7	196	50.3		100.0	100.0

Source: own computation based on survey (2022)

Table 12 classifies households into three food security categories: Stable Food Secure, Chronic Food Insecure, and Transient Food Insecure. It compares these categories between non-adopters and adopters of a specific intervention. All four households identified as stable food secure are adopters, while no non-adopters are in this category. This clear distinction indicates that adopting the intervention is linked to achieving stable food security, emphasizing its effectiveness.

Table 12 also reveals that among 141 households identified as chronically food insecure, 120 (85.11%) are adopters of the climate change adaptation strategies, while 21 (14.89%) are non-adopters. Although a significant majority of adopters continue to experience chronic food insecurity, the proportion of non-adopters in this group is notably lower. This suggests that the existing climate change adaptation practices may help reduce chronic food insecurity. In the context of transient food insecurity, 228 out of 245 households fall into the adopter category, representing 93.06%, while 17 households are classified as non-adopters, accounting for 6.94%. This implies that, despite facing considerable levels of transient food insecurity, the majority of adopters are still in a more favorable position than non-adopters, who experience significantly fewer fluctuations in food security.

Table 12. Food security status among adopters and non-adopters

Status of Food Security	Adoption Status				χ^2	Total	
	Adopters		Non-Adopters				
	No.	%	No.	%		No.	%
Stable food secure	4	100	0	0		4	1.03
Chronic food insecure	120	85.1	21	14.9	6.876***	141	36.15
Transient food insecurity	228	93.1	17	6.9		245	62.82

***significant at the 1% probability levels. Source: own computation based on survey (2022)

4.2. Econometrics Analysis

The preceding section discussed a comprehensive overview of the relationship between explanatory variables and household adoption status. However, it does not offer a quantitative understanding of the impact of these adaptation strategies on farm households' welfare. In this sub-section, the descriptive analysis is enhanced by incorporating an econometric assessment. For this specific econometric analysis, the study utilized the STATA Version 15.0 statistical package. Initially, a multivariate probit model was used to analyze the factors affecting the choice of climate change adaptation strategies. Additionally, the study estimates the impact of climate change adaptation strategies on the welfare of farmers using MESRM, METEM, and the quantile moment approach.

4.2.1. Determinants of Farmer's Choice of Climate Change Adaptation Strategies: The MVP Model Results in Adaptation Decisions

The issue of climate change and variability has become increasingly pertinent in recent years, particularly within the agricultural sector. As farmers grapple with the uncertainties associated with changing climatic conditions, it becomes essential to understand the factors influencing their adaptation practices. In this section, the study utilized the multivariate probit model to investigate these factors and provide insights into farmers' decision-making processes when adapting to climate change and variability. The findings of this study are significant, as they identify key factors that can inform the design of targeted interventions and policies to enhance farmers' adaptive capacity. This empowers policymakers and agricultural stakeholders with the knowledge they need to make effective decisions in the face of climate change.

Prior to estimating the model parameters, it was crucial to check for any issues with multicollinearity. Two tests were conducted: the variance inflation factor (VIF) for continuous explanatory variables and the contingency coefficients test for discrete explanatory variables. These tests helped assess the level of correlation between the explanatory variables, which is necessary for accurate and reliable model estimates. According to Gujarati (2012), weak associations between variables are indicated when VIF values are less than ten, and the coefficient of correlation among repressors is less than 0.8. This suggests that the variables have low explanatory power and do not strongly impact each other. Fortunately, the tests revealed no severe problems with multicollinearity among the explanatory variables. Since the problem of heteroscedasticity is common in cross-sectional data (Greene, 2008), robust standard error estimations are applied to correct any heteroscedasticity because the usual standard errors are unusable, most negligible for non-homoscedasticity (Wooldridge, 2002). Some continuous variables, such as age, family size, livestock ((TLU), farm size, distance to market, and climate perception, were logged to make them more homogenous. This was done to ensure that the variables were on a similar scale and to reduce the influence of extreme values.

Table 13 displays the estimated outcome of the MVP model. The Wald test $(\chi^2(72) = 227.68, \mathrm{p-value} < 0.0001)$ indicates a high level of significance at the 1% threshold, demonstrating the joint significance of the model's coefficient subset. Furthermore, the explanatory power of the factors incorporated into the model is reasonably strong. The results of the likelihood ratio test $(\chi^2(6) = 39.3798, \mathrm{p-value} < 0.001)$ offer strong evidence to reject the null hypothesis that the covariance of the error terms across equations is not correlated, thereby providing support for the estimation of all equations simultaneously through the MVP model, as opposed to the estimation of individual equations. The correlation between the error terms of the adoption equations shown in Table 13 confirms the interdependence assumption between the different adaptation options. The estimated correlation coefficients among the various adaptation options are significant for seven out of 6 combinations, where two coefficients have positive signs, and the remaining two have negative sign.

Table 13. Correlation coefficients for MVP regression equation.

	ρ_{CD}	ρ_{IV}	ρ_{SWC}	ρ_{LPD}
ρ_{CD}	1			
ρ_{IV}	-0.249*** (0.088)			
ρ_{SWC}	0.371*** (0.082)	-0.345*** (0.086)		
ρ_{LPD}	0.151* (0.091)	-0.006 (0.095)	0.088 (0.087)	1
Predicted probability	0.47 (0.22)	0.36 (0.19)	0.41 (0.15)	0.35 (0.18)
Joint probability (success)	0.03 (0.035)			
Joint probability (failure)	0.14 (0.108)			
Number of simulations	100			
Number of observations	390			
Likelihood ratio test of $\rho_{IVCD} = \rho_{SWCCD} = \rho_{LPDCD} = \rho_{SWCIF} = \rho_{LPDIV} = \rho_{LPDSWC} = 0$: $\chi^2(6) = 39.3798$ $Prob > \chi^2 = 0.0000$				

***P<0.01; **P<0.05, *P<0.1. Standard errors in parentheses.

The findings derived from the MVP model are presented in Table 14, providing an in-depth analysis of the various factors that influence smallholder farmers' selection of strategies to adapt to climate change.

Household Characteristics

The characteristics of the farm household determine whether or not farmers are willing to adjust their farming methods and what sort of adaptation measures they are likely to take. Consistent with Setsoafia *et al.* (2022), Abayineh and Belay (2017), and Temesgen *et al.* (2011), this study confirms that male-headed households are more likely to take up soil and water conservation practices as an adaptation option. This finding is significant as it aligns with the labor-intensive nature of these practices, making them more feasible for male-headed households. In contrast, female-headed households face constraints due to labor availability, which hinders their adaptation efforts. This finding has direct implications for policymakers and practitioners, highlighting the need for gender-specific interventions in climate change adaptation strategies.

Recent empirical evidence shows that education significantly enhances labor quality, fosters a proactive approach to adopting new technologies, and reduces uncertainties (Sahoo and Moharaj, 2024). This study reveals a notable positive correlation between the education level of the household head and both the adoption of improved crop varieties and the diversification of livelihood portfolios. This suggests that literate households are more likely to engage in the utilization of enhanced crop varieties and diversify their livelihoods compared to their illiterate counterparts. This is consistent with the findings of Abayineh and Belay (2017) and Dessalegn *et al.* (2023) suggests that education can empower farmers to engage with various agencies that promote climate change adaptation choices, thereby reducing their vulnerability to climate change and variability. This finding provides a clear direction for future research and policy interventions, emphasizing the need for educational initiatives in climate change adaptation strategies.

Resource constraints and market access

In the literature, availability, and access to resources have been extensively identified as influential factors in farmers' adaptive decisions. This study's results further illuminate this, showing that the coefficient of the livestock size (measured in tropical livestock units, TLU) variable has a significant positive influence on farmers' decision to practice crop diversification as adaptation measure. This finding aligns with the ideas of Abrham *et al.* (2022), Alem *et al.* (2016), Issahaku and Abdulai (2020), and Chilot (2007), who suggested that livestock is often regarded as an asset that can be used in the production process or exchanged for cash or other productive assets, and so plays a vital role in the adoption of appropriate adaptation measures to counteract climate change.

Without a doubt, the land, as a fundamental physical resource, is a key determinant in shaping farmers' adaptive decisions. The result of the multivariate probit model underscored that farm size is positively and significantly affect the likelihood of adopting improved crop varieties, and soil and water conservation, strategies. This is because farm size acts as a proxy variable for the availability of physical capital for the household, enabling the farm household to better bear potential risks associated with the adoption of practices and potentially finance the purchase of inputs, such as fertilizer (Menale *et al.*, 2012). This finding is in line with the research of Ojo and Baiyegunhi (2019), Abid *et al.* (2015), Mulatu (2014), and Tessema *et al.* (2013). However, farm size is inversely related to implementing livelihood portfolio diversification. This suggests that households with extensive land holdings rely on agriculture rather than diversifying their livelihood activities to meet their needs. One possible explanation for this result is that farm households with large landholding sizes in the study area can follow agricultural expansion to produce more and enhance farm income.

The parameter estimates of the distance of the input-output market from the household dwelling variable are found to be negative and statistically significant for the household's choice of livelihood portfolio diversification strategy. This underscores the impact of market proximity on farmers' decision-making processes. When farmers are far from the market, there is a reduced probability of diversifying their livelihood strategy due to less access to market-related information and access to different off-farm and non-farm livelihood strategies. Several previous studies (Abayineh and Belay, 2017; Abid *et al.*, 2015) have yielded similar results, underscoring the crucial role of market proximity in farmers' decision-making processes.

Institutional factors

In line with prior expectations, frequent extension visits by the extension agents had a positive effect on the adoption of crop diversification, and improved crop varieties, indicating that farming households that received frequent information from extension agents are shown to be more likely to adapt to climate change. Previous research by Ademe *et al.* (2019), Ojo and Baiyegunhi (2019), and Mulatu (2014) supports the idea that providing farmers with regular extension services, such as technical advice, input supply, and market information, is essential for helping them adopt climate-resilient adaptation strategies effectively.

Access to climate information on climate change has a crucial role in determining farmers' adaptation strategies. The MVP analysis shows that farmers' access to information on climate change has a positive and significant impact on crop diversification and improved variety as a climate change adaptation strategy. This is because providing farmers with information on climate change is likely to increase their awareness and lead to the adoption of new technologies and adaptation techniques. This finding corroborates the ideas of Ogada *et al.* (2021), who suggested that households that receive weather forecast information are more likely to adopt crop diversification. Indeed, it is an essential precondition for farmers to adopt adaptation measures (Madison, 2006).

Farm plot characteristics

In agreement with the prior hypothesis, among the variables representing plot characteristics, farmers' perception of soil fertility, plot slope, and plots prone to erosion are identified as essential factors in determining adoption decisions. The result implies that there is a statistically significant negative effect of good soil quality on the adoption of crop diversification and improved crop variety as a climate change adaptation strategy. This suggests that poor soil-quality plots are more likely to adopt these practices. This result confirmed the findings of Mulwa *et al.* (2017), who suggest that fertile plots will more likely require lower levels of inputs to achieve the same yield level compared to older and poorer plots.

Consistent with earlier work on climate change adaptation strategies (Sisay *et al.,* 2019; Hailemariam *et al.,* 2019; Menale *et al.,* 2012; Wainaina *et al.,* 2016), the perception of plot slope is also significantly associated with the application of soil and water conservation, and crop diversification strategies. This implies that adopting this practice is less likely on plots with flat slopes. Regarding farmers' perceptions of plots prone to erosion, results indicate that soil and water conservation practices are more likely to be used on plots suspected of erosion. Several studies confirm these results, such as those by Abdulai and Huffman (2014), Paulos and Belay (2018), and Menale *et al.* (2012), who have separately noted that farmers are more likely to implement soil conservation strategies as adaptation strategies on parts of their agricultural land that are more vulnerable to climate change risks.

Climate Change Perception and Shock

The coefficient of the variable representing farmers' perception of the severity of risks from climate shocks is positive and significantly influenced farmers' decision to adapt to climate change using improved crop varieties, soil and water conservation practices, and portfolio livelihood diversification. It aligns with a study by Di Falco and Veronesi (2013) that examined the impact of different adaptation strategies on net crop revenues in the Nile basin of Ethiopia, supporting the idea that exposure to extreme weather events like floods and hailstorms increases the likelihood that farmers will choose soil and water conservation and crop-watering strategies. This could be because farmers' short-term experiences alter perceptions of long-term patterns, which enhances adopting adaptation measures. Farmers’ perceptions and attitudes toward climate change and variability support the diversification of livelihood portfolios as an effective adaptation strategy. This tendency may stem from enhanced household awareness of climate change, which fosters behavioral changes aimed at mitigating its effects (Dessalegn *et al.,* 2023). This finding is consistent with Ruiz *et al.* (2020), who indicated that public perception of climate change can both facilitate and impede the adoption of various strategies and policies.

Table 12. Coefficient estimates of the multivariate probit model

Explanatory variables	CD		IV		SWC		LPD	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
Household characteristics								
Gender	0.127	0.172	-0.131	0.175	0.339**	0.170	-0.103	0.171
Age	0.042	0.254	0.053	0.261	0.258	0.252	0.290	0.263
Education	-0.068	0.106	0.218**	0.106	0.003	0.101	0.245**	0.105
Family size	-0.065	0.118	-0.057	0.120	0.053	0.115	0.050	0.120
Resource constraints and market access								
Livestock	0.227***	0.070	-0.082	0.070	0.089	0.067	0.111	0.071
Farm size	0.153	0.116	0.624***	0.132	0.015**	0.112	-0.274**	0.117
Credit	0.189	0.140	0.001	0.143	-0.063	0.137	0.060	0.142
Distance	-0.036	0.069	-0.050	0.071	0.065***	0.068	-0.265***	0.070
Institutional factors								
Extension	0.320**	0.144	0.421***	0.148	0.012	0.140	-0.061	0.145
Membership	-0.057	0.144	0.233	0.146	-0.020	0.139	-0.131	0.144
Climate inf.	0.283*	0.147	0.416***	0.148	-0.140	0.145	0.033	0.150
Farm plot characteristics								
Good soil	-0.785***	0.189	-0.322*	0.190	0.233	0.186	0.120	0.186
Moderate soil	-0.016	0.198	-0.126	0.200	0.115	0.197	-0.214	0.203
Slope flat	0.226	0.178	0.049	0.186	-0.491***	0.175	0.223	0.183
Moderate slope	-0.442**	0.194	-0.009	0.199	-0.016	0.188	0.250	0.196
erosion	0.040	0.141	-0.205	0.146	0.414***	0.138	0.193	0.143
Climate change perception and shock								
Climate shk	0.148	0.100	0.189*	0.103	0.229**	0.099	0.397***	0.103
Climate prc.	0.129	0.145	0.320**	0.152	-0.128	0.142	0.171	0.150
_cons	-0.397	1.016	-0.841	1.038	-2.054**	1.010	-1.423	1.045

*, ** and *** indicate statistical significance at 10%, 5% and 1%, respectively

4.2.2. Analysis of Climate Change Adaptation Strategies and their Impacts on Household Welfare

4.2.2.1. Adoption of climate change adaptation strategies in combination

The local people have implemented a variety of strategies to adapt to climate change and minimize its negative impacts in the studied area. Following the framework proposed by Mintewab *et al.* (2021), this study categorizes the four climate change adaptation strategies mentioned earlier. These strategies, which are practical and applicable in the study area, are grouped into crop management strategies, soil and water conservation measures, and livelihood diversification strategies. The crop management strategies, for instance, include crop diversification and the use of drought-resistant crop species (improved crop varieties), which can be easily adopted by farmers to adapt to changing climate conditions. Soil and water conservation measures, such as stone bunds, soil bunds, and terraces, are simple yet effective in preventing soil erosion and conserving water. Lastly, the livelihood diversification strategy, which involves on-farm, non-farm, and off-farm activities, can provide farmers with alternative sources of income.

As can be seen in Table 15, crop management practices, soil and water conservation measures, and livelihood portfolio diversification strategies are considered response or choice variables. Each farm household is queried with a dichotomous question (yes or no) regarding implementing particular adaptation strategies on their field plots. These specific climate change adaptation strategies can be used alone or in combination, resulting in eight (2^3) potential adoption options. These combinations include a combination of all climate change adaptation strategies ($A_1S_1L_1$), a combination of soil and water conservation measures and livelihood portfolio diversification ($A_0S_1L_1$), livelihood portfolio diversification ($A_0S_0L_1$), soil and water conservation measures ($A_0S_1L_0$), a combination of crop management practices and livelihood portfolio diversification ($A_1S_0L_1$). The other categories included in the study were a combination of crop management practices and soil and water conservation measures ($A_1S_1L_0$), crop management practices ($A_1S_0L_0$), and those who did not practice any of these methods ($A_0S_0L_0$).

The table reveals the resourcefulness of the farmers in the study area, who have employed a variety of climate change adaptation strategies. Notably, 22.3% of households have ingeniously combined crop management practices and soil and water conservation measures, demonstrating their recognition of the interconnectedness of agriculture and natural resource management in the context of climate change. Another 17.2% of the households are focusing on crop management practices alone, indicating a significant portion of participants are primarily improving agricultural practices as a means of climate change adaptation.

Another interesting finding is that the most commonly used combination of strategies is the implementation of all climate change adaptation strategies, which is practiced by 14.9% of the participants. This suggests that a significant portion of the participants are taking a comprehensive approach to addressing climate change. The combination of crop management practices and livelihood portfolio diversification is employed by 12.1% of the participants, indicating that many households are combining agriculture-focused strategies with diversifying their income sources. Additionally, 9.5% of households are implementing soil and water conservation measures alone, indicating that a substantial number of households recognize the importance of preserving and managing natural resources in the face of climate change. Furthermore, 7.8% of the participants practice livelihood portfolio diversification alone, indicating that a sizable portion of the participants prioritize expanding their livelihood options as a strategy for climate change adaptation. Few farmers (6.4%) utilized the combination of soil and water conservation measures and livelihood portfolio diversification. This suggests that some farmers in the study area are focusing on protecting natural resources and diversifying their sources of income to adapt to climate change.

Table 15 also reveals that 9.8% of the participants still need to implement these climate change adaptation strategies, indicating that a portion of the households may need to be made aware of or unconcerned about the impacts of climate change and the need for adaptation strategies. These findings underscore the urgency of the situation and the importance of considering multiple approaches to address the challenges posed by climate change effectively.

Table 15. Combinations of climate change adaptation practices used by farmers in the study area.

Choice	Combinations	Climate Change Adaptation Strategies: Crop Management Practice (A)	Soil and Water Conservation Measures (S)	Livelihood Portfolio Diversification (L)	Frequency	%
1	$A_1S_1L_1$	√	√	√	58	14.87
2	$A_0S_1L_1$		√	√	25	6.41
3	$A_0S_0L_1$			√	31	7.95
4	$A_0S_1L_0$		√		37	9.49
5	$A_0S_0L_0$				38	9.74
6	$A_1S_0L_1$	√		√	47	12.05
7	$A_1S_1L_0$	√	√		87	22.31
8	$A_1S_0L_0$	√			67	17.18
	Total				390	100

Each element in the adaptation practices combinations consists of a binary variable for a practice: Crop management practice(A), soil and water conservation (S), and Livelihood diversification (L) where the subscript refers 1= if adopted and 0= otherwise.

4.2.2.2. Sample the conditional and unconditional probabilities of adopting climate change adaptation strategies.

Table 1 presents the sample unconditional and conditional probabilities. The survey found that approximately 66% of the farmers had implemented crop management strategies. Furthermore, 53% of the farmers reported using soil and water management, while 41% practiced livelihood portfolio diversification. Table 16 also reveals the presence of interdependence among the three adaptation strategies. Importantly, around 70% of farmers who have already implemented crop management strategies have also adopted soil and water management measures, and 40% have embraced livelihood portfolio diversification. When considering the results, it is worth noting that the likelihood of implementing crop management practices saw a 4% increase when soil and water management measures were adopted. When farmers practice crop management techniques, the likelihood of a household adopting soil and water management measures and livelihood portfolio diversification practices is notably increased. Specifically, the probability of adopting soil and water conservation measures rises from 53% to 56%, while the probability of adopting livelihood portfolio diversification practices rises from 41% to 42%. These strategies are often interdependent and can be mutually influenced. This result is in agreement with the findings of Hailemariam *et al.* (2017) which shows that the conditional probabilities of adopting one practice given the adoption of another practice are in most cases higher than the unconditional probabilities, indicating the complementary nature of the different adaptation strategies.

Table 16. Conditional and unconditional probabilities of adopting climate change practices (%)

	Crop Management Practice (A)	Soil and Water conservation Measures (S)	Livelihood Portfolio Diversification (L)
$p(Y_j = 1)$	66	53	41
$p(Y_j = 1 \| Y_A = 1)$	100	56***	42***
$p(Y_j = 1 \| Y_S = 1)$	70***	100	40*
$p(Y_j = 1 \| Y_L = 1)$	65**	52	100
$p(Y_j = 1 \| Y_A = 1, Y_S = 1)$	100	100	40.0***
$p(Y_j = 1 \| Y_A = 1, Y_L = 1)$	100	55**	100
$p(Y_j = 1 \| Y_S = 1, Y_L = 1)$	70**	100	100

Note: $Y_j = 1$ is a binary variable representing the adoption status concerning choice j ($j = 1$ Crop management practice (A), soil and water conservation (S), and livelihood portfolio diversification (L)). *, **, and *** indicate statistical significance difference at 10%, 5%, and 1%, respectively. The comparison is between unconditional probability and conditional probabilities in each strategy.

4.2.3. Impact of Adopting Climate Change Adaptation Strategies on Household Welfare

This section presents the welfare impacts of adopting a particular climate change adaptation practice. The findings carry significant implications, as they offer valuable insights into the potential effects of implementing such strategies on household well-being. These insights can assist policymakers and stakeholders in devising effective measures to counteract the negative impact of climate change and safeguard the welfare of households.

4.2.3.1. Impact of adopting climate change adaptation strategies on farm income

Adopting appropriate adaptation practices is crucial for farmers to condense the adverse effects of climate change on their farm income, downside risk, and vulnerability to food insecurity. Understanding the impact of adopting single and combined adaptation practices is therefore of great importance. This section examines the impacts of adopting climate change adaptation practices on farm income. A two-stage multinomial endogenous switching regression (MESR) method and the STATA selmlog routine are used in the study (Bourguignon and Gurgand, 2007). The first stage of the model is critical for identifying the factors that influence farmers' choice of adaptation strategies. The appendix presents detailed results of this analysis, including the coefficients and significance levels of the explanatory variables. The estimate is under the assumption of endogenous (conditional) adoption decisions. Observed factors and unobserved heterogeneity, which could affect the adoption decisions and outcome variables, are controlled. The standard errors are bootstrapped to account for heteroscedasticity arising from the two-stage estimation procedures. In the analysis, the choices $A_0S_1L_1$ and $A_0S_0L_1$ were excluded from the estimation process because of their minimal sample sizes. The decision to exclude these choices is primarily driven by statistical considerations related to the reliability and validity of the model estimates.

Table 17 reports the average adoption effects of farm income under actual and counterfactual conditions. In this table, the farm income variable of farm households that adopted the combination of climate change adaptation practices is compared with the farm income variable that would have been found if the households had not adopted it. This is done by applying Equation (13 and 14). To determine the average adoption effects on the adopter (ATT), Columns A and B of Table 17 are compared. Column C presents the impacts of adopting climate change adaptation practices in isolation and combination on farm income, computed as the difference between the two columns.

Table 17 provides compelling evidence that the adoption of various climate change adaptation practices, whether as a single strategy or in combination, has a statistically significant and positive impact on household farm income. In every counterfactual scenario analyzed, farm households that embraced these practices would have realized lower earnings had they not adopted them. These findings not only affirm the significance of this study but also encourage further investigation into the potential of climate change adaptation strategies to enhance agricultural income.

The most notable finding was that adopting all three strategies ($A_1S_1L_1$) results in the highest farm income. By implementing these combined practices, it is possible to achieve an increased farm income of Birr 12,107, which surpasses any other combination, including the implementation of soil and water conservation measures alone ($A_0S_1L_0$), yielding Birr 9,179. The highest farm income gain for $A_1S_1L_1$ suggests that a comprehensive and integrated approach to address climate change challenges, optimize resource management, reduce risks, and ensure long-term sustainability offers a promising path forward. This finding aligns with the research of Di Falco and Veronesi (2013) in Ethiopia, who found that two climate change adaptation strategies, soil conservation and changing crop varieties, provide more payoff when combined with another climate change adaptation. The highest farm income gain for $A_1S_1L_1$ suggests that

The results, as shown in Table 17, also indicate that the joint implementation of crop management practices with soil and water conservation measures as a climate change adaptation strategy has been found to have a positive and significant impact on farm income. However, it exhibits relatively less effect on farm income (Birr 6,600). This result can be attributed to the complementarity effects of improved fertilization and pest control, which enhance crop yields, and soil and water conservation measures, which ensure the sustainability of these increased yields. This implies that farmers can significantly increase their farm income by adopting these practices in combination. This finding is consistent with that of Issahaku and Abdulai (2020) who revealed that adoption of crop choice and soil and water conservation leads to higher crop revenues.

According to Table 17, the farm income outcomes for farmers adopting different climate change adaptation practices reveal significant disparities in financial benefits. Specifically, farmers who rely exclusively on crop management strategies may overlook the enhanced gains achievable through a broader integration of techniques. For instance, those implementing only crop management practices ($A_1S_0L_0$) generate an average farm income of Birr 7510. While this approach does yield a moderate-income increase, it falls short of the potential benefits associated with incorporating additional methods. In contrast, farmers who adopt both crop management and livelihood portfolio diversification practices ($A_1S_0L_1$) experience a substantial rise in average income, increasing to Birr 8,525. This stark difference illustrates that embracing diverse strategies can significantly enhance economic outcomes. This finding aligns with the results reported by Habib *et al.* (2023) who showed that diversifying livelihoods reduces poverty by improving food security and nutrition, increasing income levels, promoting sustainable crop production, and enhancing climate vulnerability adaptation.

Thus, the observation suggests that implementing various practices, particularly adopting all three strategies, does achieve the highest farm income, leading to a significant rise in farm income for farmers. This highlights the significance of incorporating various strategies to boost farm income instead of solely depending on one practice.

Table 17 also provides the unconditional average effects of adopting climate change adaptation measures on farm income derived from the actual and counterfactual distributions. The results show that farm households that implement climate change adaptation techniques, either in isolation or in combination, generally experience higher levels of farm income than those who do not adopt such strategies. The most considerable farm income (Birr 44,207) is obtained from adopting all three strategies jointly **(**$A_1S_1L_1$**)**. However, it is essential to note that these results only indicate the effects of adopting climate change adaptation practices. They could be misleading due to selection bias from observed and unobserved factors.

Table 13. MESR based average treatment effects of adoption of climate change adaptation strategies on household farm income

Outcome	Adoption decision: If adopters adopted (A)	Adoption decision: If adopters had not adopted (B)	Average treatment effects (C)	Adoption decision: If non-adopters adopted	Adoption decision: If non-adopters had not adopted	Average treatment effect on the untreated
$A_1S_1L_1$	33135.77 (1419.72)	21028.5 (2270.88)	12107.27***	65805.68 (3327.98)	21601.58 (891.54)	44204.1***
$A_0S_1L_0$	29879.77 (1601.93)	20700.6 (2667.65)	9179.16***	32429.51 (779.47)	21601.58 (891.54)	10827.93***
$A_1S_0L_1$	30898.02 (1305.81)	22372.62 (2250.91)	8525.39***	23768.33 (627.89)	21601.58 (891.54)	2166.75***
$A_1S_1L_0$	30667.96 (634.95)	24067.67 (1876.49)	6600.29***	29681.54(387.81)	21601.58 (891.54)	8079.96***
$A_1S_0L_0$	28600.57 (823.79)	21090.37 (2194.77)	7510.2***	27613.02(355.99)	21601.58 (891.54)	6011.45***

Note: Standard errors are in parenthesis. *** and ** indicate statistical significance at the 1% and 5% levels.

4.2.3.2. Impact of climate change adaptation strategies on downside risk exposure

This section delves into a novel area of research, reporting and discussing the impact of climate change adaptation strategies on downside risk exposure**.** The findings presented in Table 18 offer valuable insights into the efficacy of various adaptation strategies in reducing downside risk and improving the stability of farm incomes. The average treatment effects in Column C of Table 18 demonstrate the impact of adaptation on downside risk exposure while addressing the selection bias that may arise from the systematic differences between adapters and non-adapters (Abdulai and Huffman, 2014).

It is noteworthy that implementing individual strategies, such as crop management practices, soil and water conservation, and livelihood portfolio diversification, either alone or in combination, results in a statistically significant increase in the skewness of farm income, indicating a reduction in downside risk. The results in Table 18 indicate that implementing all three strategies simultaneously ($A_1S_1L_1$) results in the most substantial increase in farm income skewness, thereby achieving the greatest reduction in downside risk, with a 39% increase compared to the counterfactual scenario where none of the strategies are implemented. This finding is consistent with the observations of Issahaku *et al.* (2021), who noted that employing a combination of adaptation strategies may yield greater benefits in terms of on-farm performance (output, variance, and skewness) compared to using individual strategies. This is likely because the integration of different adaptation strategies, such as crop diversification, soil and water conservation, and livelihood diversification, creates a more diversified portfolio that mitigates overall risk exposure. As a result, this diversification helps to stabilize the income flow and diminishes the likelihood of extreme negative outcomes, ultimately reducing downside risk.

When soil and water conservation methods are implemented in isolation ($A_0S_1L_0$), there is a noticeable 28% increase in skewness, indicating a significant reduction in downside risk. This finding is consistent with Shahzad *et al.*'s (2021) study, which concluded that adopting soil and water conservation methods reduces farmers' exposure to downside risk and the probability of crop failure. However, when these practices are combined with crop management, the decrease in downside risk exposure is lower (18%) compared to implementing each method alone. This inconsistency may arise because, although soil and water conservation practices can enhance soil structure and fertility, their effectiveness is contingent upon the alignment of crop management practices, such as crop selection and planting techniques. This result reflects those of Bekele *et al.* (1998), who also noted that the mere adoption of soil conservation technologies is insufficient to boost agricultural productivity; rather, these technologies must be integrated with supportive crop management practices to fully leverage their benefits.

Adoption of crop management practices in isolation ($A_1S_0L_0$), and in combination with livelihood portfolio diversification practices ($A_1S_0L_1$) both result in a significant reduction in downside risk, with decreases of 23% and 15%, respectively. This outcome can be attributed to the combined impact of these adaptation strategies in enhancing the overall risk management and coping capacity of farming households. For example, livelihood diversification can provide alternative income sources during periods of crop failure or low yields, thereby reducing downside risk. These findings are supported by previous research emphasizing the role of livelihood diversification in strengthening resilience among farming households (Barrett *et al.,* 2001; Ellis, 2000).

Table 14. Average treatment effects of adopting individual and combined strategies on downside risk exposure.

	Adoption decision				Adoption decision			
Outcome	If adopters adopted (A)	If adopters had not adopted (B)	Average treatment effects on treated (ATT) (C)	Change in outcome (%)	If non-adopters adopted	If non-adopters had not adopted	Average treatment effect on the untreated (ATU)	Change in outcome (%)
$A_1S_1L_1$	1.037 (0.022)	0.744 (0.056)	0.293***	39.4	1.313 (0.021)	0.816 (0.022)	0.499***	61.1
$A_0S_1L_0$	1.013 (0.018)	0.79 (0.069)	0.223***	28.2	1.071 (0.009)	0.8162 (0.022)	0.255***	31.3
$A_1S_0L_1$	1.015 (0.013)	0.882 (0.059)	0.134***	15.1	0.925 (0.008)	0.816 (0.022)	0.109***	13.4
$A_1S_1L_0$	1.01 (0.008)	0.85 (0.043)	0.16***	18.8	0.989 (0.005)	0.816 (0.022)	0.173***	21.2
$A_1S_0L_0$	0.976 (0.013)	0.791 (0.0495)	0.1854***	23.4	0.978 (0.007)	0.816 (0.022)	0.162***	19.9

Note: Standard errors are in parenthesis. *** and * indicate statistical significance at the 1% and 10% levels.

4.2.3.3. Impact of adaptation to climate change on the household's vulnerability to food insecurity.

In this section, the study emphases on analyzing the impact of climate change adaptation strategies on vulnerability to food insecurity using METE model. However, we need to delve into the factors that affect adopting these strategies, which is the first stage of the METE model. The estimation results for the first stage are included in appendix Table 12. By quantifying the potential effects, policymakers and farmers can make informed decisions regarding which practices to adopt to enhance their economic resilience and food security.

Table 19 presents the findings of the multinomial endogenous treatment effects analysis, which examines the impact of climate change strategies on vulnerability to food insecurity. Notably, several selection correction terms that address potential data biases are highly significant at the 1% threshold. This suggests that adopting combinations of climate change adaptation practices will have a different effect on non-adopters, should they adopt. Results show that, in almost all cases, adopting a single and joint adaptation strategy significantly reduces the probability of vulnerability to food insecurity in many of the outcome variables considered. This implies that farmers need to practice climate change adaptation strategies on their farms to reduce susceptibility to food insecurity in uncertain climate change events.

The results, as shown in Table 19, show that the combined use of all the climate change adaptation strategies ($A_1S_1L_1$) and the adoption of crop management practices alone ($A_1S_0L_0$) both result in a decrease in the likelihood of vulnerability to food insecurity. The reduction in vulnerability is 18% and 21% points lower, respectively, compared to non-adoption. More importantly, the highest reduction in the probability of vulnerability to food insecurity (26% points) is realized through adopting soil and water conservation measures in isolation ($A_0S_1L_0$). These findings are particularly relevant for farmers in the study area, where climate change is a significant threat to food security. This demonstrates that implementing soil and water conservation measures can enhance the resilience of cropping systems against climate change-induced water stresses such as floods and droughts. These results confirm earlier findings by Million *et al.* (2019) for farmers in eastern Ethiopia that adopting soil and water conservation practices significantly reduces the probability of farmers being food insecure, vulnerable to food insecurity, and transient and chronically food insecure.

Adoption of crop management practices in combination with soil and water conservation measures ($A_1S_1L_0$) also provides the highest reduction in the probability of vulnerability to food insecurity (14% points). than a combination of livelihood portfolio diversification strategies ($A_1S_0L_1$) (6%). This result is probably because the use of inputs and resources, such as improved seed varieties, proper fertilizer application, and pest and disease management techniques, can significantly increase crop productivity. By implementing soil and water conservation practices like terracing, contour plowing, and mulching, the fertility of the soil is maintained, leading to healthier crops and higher yields. This increased productivity ensures a more stable food supply and reduces vulnerability to food insecurity. Previous studies (Mussa, 2022; Herrera *et al.,* 2021; Mango *et al.,* 2018) show that adopting different agricultural technologies would likely positively impact crop yield, consumption expenditure, food security, and alleviating poverty.

Hence, adopting climate change adaptation measures can improve crop production's environmental and economic aspects. This allows farmers to spend more on food items than they would have if they had not adopted the practices.

Table 15. Multinomial endogenous treatment effect estimates of adoption impacts of climate change adaptation strategies on vulnerability to food insecurity.

Outcome Variable	Strategy Choice	Coefficient	Standard Error
Vulnerability to Food Insecurity	$A_1S_1L_1$	-0.18***	0.003
	$A_0S_1L_0$	-0.26***	0.002
	$A_1S_0L_1$	-0.06***	0.003
	$A_1S_1L_0$	-0.14***	0.008
	$A_1S_0L_0$	-0.21***	0.007
	Selection terms		
	$^{\lambda}A_1S_1L_1$	0.059***	0.0008
	$^{\lambda}A_0S_1L_0$	0.168***	0.0006
	$^{\lambda}A_1S_0L_1$	-0.014***	0.0007
	$^{\lambda}A_1S_1L_0$	0.094***	0.0008
	$^{\lambda}A_1S_0L_0$	0.244***	0.0006

*** denotes significance at 1% significance levels.

4.2.3.4. Impact of climate change adaptation practices on the cost of risk

Ensuring the sustainability of agricultural systems requires effective management of the costs associated with climate change risks. As farmers adopt various adaptation practices, it becomes essential to assess their impact on these costs. This study employs the quantile moment approach, a widely recognized and robust methodology in risk analysis, to evaluate how both individual and combined adaptation strategies influence the cost of risk. This approach utilizes statistical moments, such as variance (which measures the distribution's spread) and skewness (which captures the distribution's asymmetry), to provide a comprehensive understanding of risk shape and distribution. By offering reliable insights into the economic implications of different adaptation strategies, this analysis equips policymakers with the necessary information to make informed decisions. Ultimately, these findings contribute to the development of cost-effective climate change adaptation policies, enhancing the resilience of agricultural systems against evolving climate challenges.

Table 20 presents the distribution of farm income, encompassing measures of variance and skewness. Notably, 56% of the unconditional farm income distribution is concentrated to the left of the mean, indicating a negative skewness. This negative skewness is accompanied by greater variance in the case of non-adoption compared to instances where adaptation practices are implemented.

The empirical results discussion commences with an analysis of the skewness properties of the farm income distribution. The Bera-Jarque test for normality of the error term e indicates that the skewness of e is statistically significant deviation from zero with a P-value of 0.0001, providing strong support for rejecting the null hypothesis that the skewness of the error term is equal to zero. This implies that the error term differs from a symmetric or normal distribution, displaying a notable skewness.

It is observed that the lower tail exhibits a quantile skewness of -1.04, while the upper tail shows a quantile skewness of 1.33. This finding suggests that extreme events or outcomes are likely to occur frequently in the agricultural sector of the study area, which faces significant unpredictability due to climate change. Furthermore, the quantile moments of the error term indicate that the 1st and 4th quantiles (representing the lower and upper tails of the distribution) have substantially higher variances ($2.95E+10^7$ and $7.57E+10^7$, respectively) compared to the 2nd and 3rd quantiles ($2.01E+10^6$ and $4.19E+10^6$, respectively). The elevated variances in the 1st and 4th quantiles reflect a broader dispersion of farm income values within these groups.

Table 16. Distribution of farm household income by variance, and skewness.

Quantiles	Variance	Skewness
1st quantile	$2.95E+10^{7}$	-1.04
2nd quantile	$2.01E+10^{6}$	0.149
3rd quantile	$4.19E+10^{6}$	0.283
4th quantile	$7.57E+10^{7}$	1.33

Source: Own computation

The unconditional farm income density distributions by practice illustrated in Figure 8 provide further evidence for these findings. The distributions clearly show negative skewness and greater variance for non-adoption compared to cases where adaptation practices have been adopted. This reinforces the significance of adopting climate change adaptation strategies to enhance income stability among farmers.

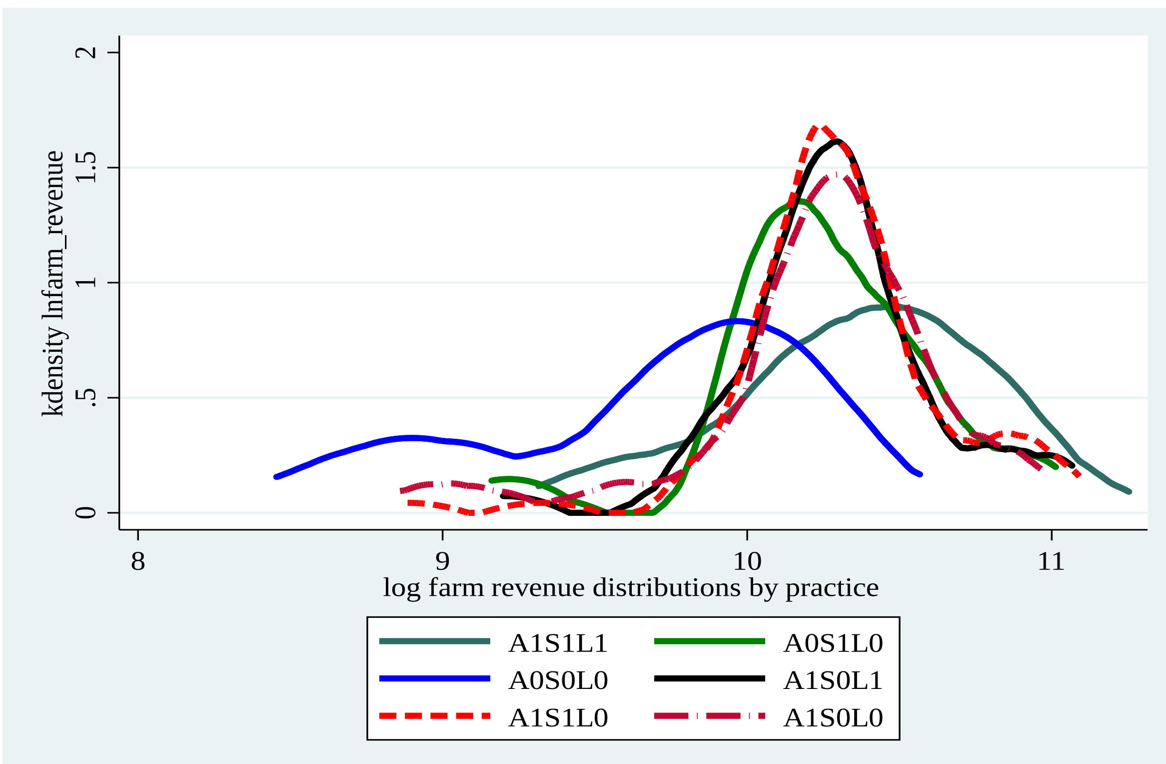

Figure 8. Unconditional Farm Income Density Distribution.

Table 21 summarizes the findings regarding the link between climate change adaptation practices and the cost of risk. The cost of risk for each choice is dissected into variance and skewness components. Specifically, this is done by separating second and third-moment effects in the risk valuation as summarized in equation (26). Following Yesuf and Bluffstone (2009) and Kim *et al.* (2014), this study explores scenarios across a range of constant relative risk aversion values, from moderate (b = 2) to low (b = 1). These ‘b’ values serve as indicators of risk aversion, with higher values indicating greater aversion to risk. This approach allows for an analysis of how the cost of risk and its decomposition change with varying levels of risk aversion.

The data in Table 21 show that not adopting climate change adaptation practices leads to significantly higher risk costs than adopting such strategies. The most substantial reduction in costs of risk occurs when farmers combine portfolio diversification with crop management practices ($A_1S_0L_1$) and adopt soil and water conservation practices in isolation ($A_0S_1L_0$), resulting in a risk premium of only 6.52, and 6.55, respectively, under the lower-case scenario. Under the moderate case scenario, these strategies' total risk premiums are 15.7 and 15.72. This finding highlights the effectiveness of livelihood diversification strategies; by broadening income sources, such as incorporating off-farm activities, farmers can mitigate risk and stabilize overall household income. This diversification significantly reduces both variance and skewness in income distribution, leading to a lower overall cost of risk. These findings align with Menale *et al.* (2015), which identifies Sustainable Intensification Practices (SIPs) as effective in managing risks under challenging conditions. Overall, this analysis provides valuable insights for farmers and policymakers, illustrating the potential benefits of targeted adaptation strategies in minimizing risk costs.

Conversely, the crop management practices-only option ($A_1S_0L_0$) presents a smaller reduction in costs of risk, with risk premiums of 12.58 and 31.07 for low and moderate risk aversion, respectively. This smaller reduction can be attributed to the focused nature of crop management practices such as adjusting planting dates, utilizing drought-resistant varieties, and implementing integrated pest management, which primarily address risks within the crop production system. While these practices enhance crop yield resilience, they fall short of addressing other significant risks faced by households, such as income volatility, livestock losses, and disruptions in secondary livelihood activities. This limited scope of risk mitigation in crop management alone results in a higher overall cost of risk, aligning with the observations of Hellin *et al.* (2009), which emphasize the vulnerabilities of relying solely on crop management practices.

Additionally, Table 21 underscores that relying solely on second-moment information (variance) is insufficient when analyzing the lower tail of the distribution (Kim *et al.,* 2014). In this range, the assessment of risk premium is significantly affected by third-moment effects (skewness), which constitute a considerable portion (55%) of the risk premium under moderate scenarios. Similar to findings by Menale *et al.* (2015) and Kim *et al.* (2014), downside risk is more pronounced in the cost of risk for non-adoption compared to the adoption. On average, downside risk accounts for 54% of the total risk premium under both joint and individual adoption of practices, while this figure rises to 58% for non-adoption under moderate scenarios. The remaining costs of risk stem from the variance component of farm income distribution. Overall, the analysis emphasizes that the adoption of climate change adaptation strategies significantly reduces risk exposure, leading to a decreased likelihood of crop failure and lower income variability.

Table 17. Risk premium R and its decomposition by variance and skewness components

	Lower Case Scenario (b=1)			Moderate Case Scenario (b=2)		
	Components			Components		
Choices	Variance	Skewness	TOTAL (R)	Variance	Skewness	TOTAL (R)
$A_1S_1L_1$	5.85 (53.9)	5 (46.1)	10.85	11.7 (43.8)	14.98 (56.2)	26.68
$A_0S_1L_0$	3.93 (60)	2.62 (40)	6.55	7.85 (50)	7.87 (50)	15.72
$A_0S_0L_0$	7.48 (51.9)	6.93 (48.1)	14.41	14.96 (41.8)	20.8 (58.2)	35.75
$A_1S_0L_1$	3.87 (59.3)	2.65 (40.7)	6.52	7.74 (49.3)	7.96 (50.7)	15.7
$A_1S_1L_0$	5.39 (55.5)	4.32 (44.5)	9.71	10.77 (45.48)	12.96 (54.6)	23.73
$A_1S_0L_0$	6.69 (53.1)	5.9 (46.9)	12.58	13.37 (43)	17.69 (57)	31.07

Note: Percentages of each component of risk premium is in parentheses. Both variances and skewness measures are rescaled by dividing by1,000

5. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1. Summary

Agriculture, the backbone of most agrarian economies like Ethiopia, is the key to poverty reduction and economic development. However, it has its challenges. It is highly vulnerable to climate change and variability, significantly affecting farmers' livelihood outcomes. Climate change and variability will likely put significant additional stress on agricultural production. Yet, the resilience and adaptability of smallholder farmers, who are at the forefront of these challenges, are truly commendable. Agricultural sustainability, therefore, depends on farmers' ability to adapt their production systems to these environmental and economic shocks and changes.

This study sought to empirically assess and analyze the impact of climate change adaptation practices on smallholder farmers' welfare in the Bench Maji zone of southwest Ethiopia. In particular, the study answers the following four main research questions: (1) Do farmers perceive changes in climatic parameters and what adaptations have they employed against climate change impacts? (2) What are the determining factors that influence farmers' choice of adaptation practices to climate change and variability? (3) What is the impact of adopting single and combined climate change adaptation practices on farm income, downside risk, and vulnerability to food insecurity? (4) What is the impact of adopting single and combined climate change adaptation practices on the cost of risk? The responses to these inquiries hold significant implications for formulating policies and initiatives intended to assist farmers residing in impoverished areas in adapting to climate change's effects.

The study employed a rigorous methodology to collect data. Cross-sectional survey data was gathered through structured and semi-structured questionnaires. A multistage sampling technique was used to select a representative sample of 390 households from four climate-prone districts. The data collected included household demographic variables, socioeconomic and infrastructural factors, food consumption and spending, household wealth indicator variables, farm characteristics, and environmental factors. This comprehensive approach ensures the reliability and validity of the study's findings.

Descriptive statistics were generated to provide a comprehensive summary of the dataset's critical characteristics and address research question number one. Accordingly, Males were found to be dominant in the adoption practices, with 78% of adopters being in male-headed households. Education was the most influential factor in adapting to climate change, with 38% of respondents having no formal education. Off-farm job opportunities were limited, and 50.77% of households had no access to credit services. Frequent contact with extension agents was also found to be non-significant, with only 59.38% of adopters and 59.55% of non-adopters having contact at least six times a year. Participation in socioeconomic groups was not statistically significant between adopters and non-adopters of adaptation options. Access to early warning information was limited, with 34.1 percent of households receiving it. Physical plot characteristics influenced smallholder farmers' decision to adopt soil fertility management and conservation practices. Farm plot perceptions were also insignificant, with 46.44% of adopters and 30.51% of non-adopters having flat or moderate slopes. Soil erosion severity was perceived differently among adopters and non-adopters, with 48.72 percent of adopters and 26.32 percent of non-adopters describing their plots as severely eroded. Farmers' perceptions of risks such as drought, crop failure, climate change, and other shocks were also considered.

Smallholder farmers in the study area have employed various technical measures to reduce the adverse impacts of climate change and variability. However, their climate change awareness and perceptions influence their strategies and adaptation levels. Farmers' perceptions of rainfall and temperature variability were ranked using a five-point Likert scale. Over the past ten years, over 86%, 80%, and 90% of households recognized variations in rainfall amount, duration, and onset and cessation time of the rainy season. Temperature variability was increasing, with 40.7 percent of households recognizing it. Around 80.9 % and 84.6% of households perceived an increase in long periods of dry season and the number of hot days in their locality. A significant proportion of respondents perceived a rise in warm nights over the years, while 9.7 percent perceived a decrease in the number of warm nights yearly. Farmers' perceptions of the impact of climate change on agriculture were also examined. Nearly 56% and 55% of respondents experienced flooding and landslides, death of livestock, increased infestation of crop diseases and insects, introduction of more weeds and drying up of streams, crop yield decline, and soil degradation due to climate-related changes.

In response to long-term anticipated changes in climatic situations, smallholder farmers in the studied area have implemented several adaptation strategies, including crop diversification (52.1%), and soil and water conservation practices (44.4%). 38.2% of farmers have chosen to diversify their income sources to wage labor and collect permanent trees for sale. Soil and water conservation practices, such as terraces and soil bunds, have been implemented to mitigate potential soil erosion and loss of precipitation. Improved crop varieties (28%) are also used to boost agricultural productivity and production, increasing farm income.

The MVP model was utilized in this study to address the second research question. The overall findings suggest that adaptation methods have a significant complementary effect. The results show that male-headed households are more likely to adapt to climate change using soil and water conservation practices. Education level positively influences the adoption of improved varieties, and livelihood portfolio diversification. Livestock ownership positively and significantly influences the adoption of crop diversification. Farm size significantly and positively influences the adoption of improved crop varieties while negatively affecting livelihood diversification. The distance of the input-output market from the household dwelling variable is negative and statistically significant for the household's choice of livelihood portfolio diversification strategy. Institutional factors like frequent extension visits, and access to climate information positively impact crop diversification and improved variety adoption. Farm plot characteristics, such as soil fertility, and slope flat, and erosion risk, influence adoption decisions. Farmers perception of past climate change also positively and statistically significant influence on the adoption of improved varieties.

The answer to the third question is addressed through the MESR model. The study finds that adopting climate change adaptation practices has a positive and statistically significant impact on farm income. Combining all three strategies yields the highest farm income (Birr 12,107), indicating that a comprehensive and integrated approach effectively addresses climate change challenges and optimizes resource management. The joint implementation of crop management practices with livelihood portfolio diversification significantly impacts farm income (Birr 8525), which is also greater than the effect of each practice independently, suggesting complementarity in benefits.

The analysis also examined the impacts of implementing climate change adaptation measures on current downside risk exposure using a method that captures the third moment of farm income function as a measure of downside farm income risk. The overall findings suggest that all climate change adaptation practices, whether implemented alone or in combination, lead to statistically significant positive impacts on farm income skewness. This implies a reduction in the likelihood of crop failure or revenue loss. It has been observed that the most significant reduction in downside risk (indicated by an increase in skewness) occurs when farmers adopt a combination of strategies, resulting in a 39% increase compared to not adopting any strategies. This combined approach significantly improves income stability in the face of climate variability. Additionally, adopting soil and water conservation measures alone results in a 28% increase in farm income skewness, while adopting crop management practices also results in a 23% increase.

The METE model addresses the impact of climate change adaptation strategies on farmers' vulnerability to food insecurity. Adoption of soil and water conservation practices in isolation highly reduces the probability of vulnerability (26%) than adoption of other practices in isolation. The results also showed that adoption of crop management practices in combination with soil and water conservation measures also reduces the probability of vulnerability to food insecurity than a combination of livelihood portfolio diversification strategy. However, the largest reduction in the probability of vulnerability to food insecurity (21%) is obtained from adoption of crop management practices alone.

Finally, the answer to the fourth question is addressed through a quantile moment-based approach. The costs of risk in each choice are decomposed into variance and skewness components. The most substantial reduction in costs of risk occurs when farmers combine crop management practices with livelihood portfolio diversification ($A_1S_0L_1$), resulting in a risk premium of only 6.5 under the lower-case scenario and 15.7 under the moderate case. This finding highlights the effectiveness of livelihood diversification strategies. Conversely, the crop management practices-only option ($A_1S_0L_0$) presents a smaller reduction in costs of risk, with risk premiums of 12.6 and 31 for low and moderate risk aversion, respectively. This smaller reduction can be attributed to the focused nature of crop management practices.

5.2. Conclusions and Recommendations

The present research aimed to estimate the welfare impacts of adaptations to climate change and variability on smallholder farmers in the Bench Maji zone, southwest Ethiopia. Based on the findings of this study, the following conclusions and recommendations are drawn:

The findings of this study indicate that male-headed households play a primary role in implementing adaptation practices to address climate change. Nevertheless, it is widely acknowledged that empowering female-headed households is crucial to enhancing the adoption of these practices as effective strategies in the study area. Therefore, it is essential to dismantle social barriers that hinder female farmers from accessing information, land, and other resources that impede their ability to adopt climate change adaptation strategies. Consequently, stakeholders such as government extension services, agricultural extension workers, and non-governmental organizations should prioritize empowering female-headed farmers by creating an enabling environment for them to access inputs, credit, training, and extension services related to climate change and agriculture.

The results of this study illustrate that the educational attainment of the household head has a positive and significant impact on the adoption of improved crop varieties and livelihood diversification practices as adaptation strategies. This highlights the crucial role of improving farmers' education in the areas under study. It is therefore recommended that both local governments and non-governmental organizations enhance adult education efforts and introduce training programs for farmers focusing on adaptive strategies for climate change. This could involve conducting workshops on sustainable farming practices, income source diversification, and effective soil and water management.

The study indicates that higher livestock ownership significantly influences farmers' decisions to engage in crop diversification. Livestock, often seen as an asset, underscores the importance of improving farmers' access to financial resources and credit. Thus, policies that aimed at increasing benefits of livestock to farmers should involve working with financial institutions to develop specialized credit packages for investments in livestock feed, health care, management tools, and diversification.

The findings of this study suggest that households with larger farm sizes are more likely to adopt improved crop varieties and at the same time, they are less inclined to diversify their livelihood activities. The size of the farm, which serves as a proxy for the household's physical capital, enables farmers to manage risks better and potentially finance purchases of inputs such as fertilizer. Therefore, policies promoting adaptation to climate change at the farm level should prioritize the advantages of adaptation strategies for households with larger farm sizes.

The proximity of the input-output market to the household dwelling variable has a negative and statistically significant impact on the household's decision when it comes to diversifying its livelihood portfolio. As a result, it is important for government, NGOs, and other stakeholders to collaborate in expanding rural services, especially those directly linked to agricultural production, such as rural roads.

Institutional factors like frequent extension visits, and access to climate information positively impact crop diversification and improved variety adoption. Thus, regular and high-quality contacts between extension staff and farmers are required. This may be accomplished by providing regular training and capacity building to extension workers, ensuring that they are up to date on climate change adaptation methods and technology. Furthermore, farmers should have access to reliable and timely climatic information and predictions. This will help improve agricultural decision-making and planning, reducing the hazards associated with climatic unpredictability.

The findings of this study suggest that adopting specific climate change adaptation practices, such as crop management practices, soil and water conservation measures, and livelihood portfolio diversification strategy, has a positive and statistically significant impact on farm income. Farmers who adopt these practices, individually or in combination, experience higher farm income levels than those who do not. When considered as a whole, these results suggest that there is a need to promote and provide support for farmers through implementing training and capacity-building programs, ensuring access to credit and finance, improving rural infrastructure, and promoting value-added initiatives. These programs can help farmers gain skills for non-farm activities, improve market access, and enhance the profitability and marketability of agricultural products.

The highest farm income was achieved by adopting all three strategies together. This not only underscores the importance of a combined approach to climate change adaptation but also highlights the resilience and adaptability of the farming system. This approach boosts immediate farm income and has long-term sustainability effects. By adopting all three strategies, farmers can build a resilient farming system better equipped to face future challenges. The combined approach ensures the sustainability of both farm income and the ecosystem, as measures like soil and water conservation contribute to long-term soil health, water availability, and environmental conservation. This suggests that policy interventions should take a bundled approach, promoting the complementary adoption of different adaptation strategies rather than treating them in isolation.

The findings also emphasized the critical role of integrated strategies, particularly the comprehensive application of crop management practices, soil and water conservation techniques, and diversification of farm income streams. This combination significantly reduced the risk of crop failure and income loss amid climatic uncertainties. As a result, future interventions should take into account a larger range of risks than those addressed in existing crop management practices. Integrating measures that address income volatility, livestock management, and other livelihood activities can help farmers build a stronger safety net.

The overall results of the METE analysis seem pragmatic. The outcomes are reduced when farmers use different climate change adaptation measures than they would have if they had not adopted them. The results from the analysis suggest that adopting climate change adaptation strategies, particularly combinations of strategies, can significantly reduce vulnerability to food insecurity. It is, therefore, necessary to encourage the adoption of complementary adaptation strategies: Advise farmers to adopt a combination of adaptation strategies, as the study found that joint adoption can significantly reduce the probability of vulnerability to food insecurity. Moreover, offering guidance and training to farmers on how to effectively combine different adaptation practices, such as crop management practices, soil and water conservation measures, and livelihood diversification, can help them maximize the benefits of adopting a mix of adaptation strategies.

Additionally, creating an enabling environment to support adaptation is necessary, which includes promoting research and development, disseminating information and knowledge on climate change adaptation to farmers through extension services and other channels, and fostering collaborations between farmers, researchers, and extension service providers to facilitate the adoption of these strategies. Addressing the social, political, and institutional factors that may be contributing to food insecurity, and working with policymakers to develop and implement supportive policies, programs, and institutional arrangements can further facilitate the adoption of climate change adaptation measures by farmers.

The cost of risk analysis also revealed that non-adoption of climate change adaptation practices is associated with a considerably higher cost of risk compared to those who do adopt such strategies. Notably, the most substantial reduction in the cost of risk was observed when farmers combined crop management practices with livelihood portfolio diversification activities. To get the best outcomes, it may be necessary to combine support services: training on best practices for crop management practices, and sustainable farming methods; and access to resources such as microloans that assist farmers in effectively implementing crop management practices and livelihood portfolio diversification methods, allowing them to address difficulties holistically rather than merely via joint implementation.

5.3. Suggestions for Further Research

This study raises several unanswered questions that necessitate further investigation. Based on the outcomes and discussion of this study, recommendations for future research emerge. Consequently, the findings of this study are drawn from cross-sectional and household-level data. However, incorporating panel data analysis could provide more robust evidence on the impact of adaptation on households' farm income and downside risk exposure. This would enable a better understanding of the short- and long-term effects of adaptation strategies. Thus, future research should explore the influence of different adaptation strategies on farm output across varying time frames.

The characteristics of farmland, such as the number, slopes, and fertility of individual field plots, as well as the size of the farm and the distance to field plots, are crucial factors that influence the overall quality of the farmland. Despite their significance, these field plot-varying characteristics are often overlooked, particularly at the individual field plot level. However, they have the potential to directly or indirectly impact the adoption of climate change adaptation strategies, as well as overall farming production. As a result, it is recommended to conduct a more detailed study at the plot level to gain a deeper understanding of how the adoption of adaptation strategies varies in relation to these plot-level factors. Moreover, it is important to evaluate whether the current findings change given the influence of these factors.

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7. APPENDICES

7.1. List of Tables in Appendix

Appendix Table 1. Conversion factors used in the livestock holding

Class/ Species	TLU Conversion Factor
Oxen	1.1
Cow	1
Heifer	0.5
Young Bull	0.6
Calves	0.2
Sheep	0.1
Goats	0.1
Donkeys	0.5
Horses	0.8
Mules	0.7

Source: FAO, 1987, 1986

Note: TLU is commonly taken to be an animal of 250 kg live weight.

Appendix Table 2. Adult equivalent conversions

Age	Male	Female
0_1	0.33	0.33
1_2	0.46	0.46
2_3	0.54	0.54
3_5	0.62	0.62
5_7	0.74	0.7
7_10	0.84	0.72
10_12	0.88	0.78
12_14	0.96	0.84
14_16	1.06	0.86
16_18	1.14	0.86
18_30	1.04	0.8
30_60	1	0.82
60+	0.84	0.74
Total AD		

Source: World Development and based on a World Health organization equivalence scale quoted by Dercon (1998)

Appendix Table 3. Conversion factor for computing calorie intake

Food item	**Unit**	**Calorie**	**Food item**	**Unit**	**Calorie**
Wheat	Kg	3574	Beef	Kg	1148
Teff	Kg	3589	Milk	Litter	737
Barely	Kg	3723	Butter	Kg	7363
Lentil	Kg	3522	Egg No	NO	61
Hose bean	Kg	3514	Honey	Kg	3605
Sorghum	Kg	3805	Pepper	Kg	933
Peas	Kg	3553	Maize	Kg	3560
Vetch	Kg	3470	Millet	Kg	3260
Linseed	Kg	5109	Check pea	Kg	3630
Sugar	Kg	3850	Garlic	Kg	118
Coffee	Kg	1103	Edible oil	Kg	8964
Potato	Kg	1200	Yam(goderie)	Kg	1100
Sweet potato	Kg	1360			

Source: EHNRI, 2000

Appendix Table 4. One week food consumption levels of the sample taken during the survey in kilogram.

Food Consumption Items	Mean	Std. Dev.
Maize	1.177	0.758
Sorghum	2.040	1.315
Teff	0.268	0.172
Peas	0.825	0.532
Milk	0.043	0.028
Meat	0.001	0.001
butter	0.003	0.002
Egg	0.007	0.005
Edible oil	0.001	0.000
Sugar	0.004	0.000
Coffee	1.519	0.979
Onion	0.087	0.056
Potato	7.221	4.654
Sweet potato	16.789	10.820
Yam (goderie)	13.864	8.935
Cabbage	0.0217	0.014
Orange	0.001	0.001
Banana	0.434	0.279
Avocado	0.173	0.112
Papaya	0.236	0.152
Mango	0.001	0.001
Pepper	0.447	0.288

Source: own computation, survey (2022)

Appendix Table 5. Summary statistics of explanatory variables across an alternative combination of climate change adaptation strategies.

Variables	$A_1S_1L_1$		$A_0S_1L_1$		$A_0S_0L_1$		$A_0S_1L_0$		$A_0S_0L_0$		$A_1S_0L_1$		$A_1S_1L_0$		$A_1S_0L_0$	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Household characteristics																
Gender	0.78	0.42	0.80	0.41	0.74	0.44	0.76	0.43	0.82	0.39	0.68	0.47	0.79	0.41	0.84	0.37
Age	41.22	8.73	46.68	10.62	43.13	12.02	41.92	8.54	41.84	10.71	40.83	12.19	42.56	12.02	43.49	11.88
Education	0.83	0.70	0.88	0.67	0.90	0.70	0.84	0.50	0.47	0.60	0.87	0.58	0.87	0.76	0.45	0.61
Family Size	4.88	2.09	4.72	2.41	4.65	2.06	5.03	1.94	4.61	1.85	4.13	2.33	4.76	2.01	4.94	2.10
Resource constraints and market access																
Livestock	7.34	3.94	1.80	1.75	3.05	1.63	2.33	2.10	1.95	1.26	1.53	1.23	3.26	2.49	4.46	3.19
Farm size	1.53	0.79	1.36	0.60	1.48	0.64	1.36	0.74	1.28	0.76	1.42	0.77	1.44	0.67	1.43	0.75
Off farm	0.48	0.50	0.32	0.48	0.48	0.51	0.59	0.50	0.34	0.48	0.34	0.48	0.47	0.50	0.40	0.49
Credit	0.52	0.50	0.40	0.50	0.39	0.50	0.49	0.51	0.47	0.51	0.51	0.51	0.47	0.50	0.58	0.50
Distance	29.81	22.06	28.40	20.75	35.32	22.06	32.57	23.17	31.37	23.72	37.34	23.68	29.66	23.52	30.15	20.89
Institutional factors																
Extension	0.64	0.48	0.68	0.48	0.68	0.48	0.54	0.51	0.45	0.50	0.49	0.51	0.63	0.49	0.54	0.50
Membership	0.29	0.46	0.36	0.49	0.52	0.51	0.32	0.47	0.39	0.50	0.43	0.50	0.46	0.50	0.37	0.49
Climate info.	0.31	0.47	0.28	0.46	0.35	0.49	0.32	0.47	0.45	0.50	0.23	0.43	0.37	0.49	0.37	0.49
Farm plot characteristics																
Good soil	0.40	0.49	0.64	0.49	0.52	0.51	0.46	0.51	0.42	0.50	0.57	0.50	0.52	0.50	0.36	0.48
Moderate soil	0.41	0.50	0.24	0.44	0.29	0.46	0.16	0.37	0.47	0.51	0.30	0.46	0.30	0.46	0.45	0.50
Slope flat	0.33	0.47	0.44	0.51	0.48	0.51	0.30	0.46	0.39	0.50	0.45	0.50	0.64	0.48	0.55	0.50
Moderate slope	0.31	0.47	0.40	0.50	0.26	0.44	0.32	0.47	0.42	0.50	0.32	0.47	0.22	0.42	0.31	0.47
Erosion	0.45	0.50	0.52	0.51	0.48	0.51	0.59	0.50	0.26	0.45	0.40	0.50	0.70	0.46	0.36	0.48
Climate change perception and shock																
Climate shock	0.72	0.72	0.68	0.75	0.90	0.65	0.97	0.69	0.42	0.64	0.98	0.64	0.78	0.77	0.87	0.67
Climate perc.	1.05	0.39	0.83	0.38	0.86	0.35	1.06	0.40	0.86	0.34	1.01	0.45	1.04	0.43	1.12	0.40

Source: own computation, survey (2022)

Appendix Table 6. Variance inflation factor

Variables	VIF	1/VIF
Age of hh	1.022	.978
Family size	1.019	.982
Distance to market	1.014	.986
Climate perception	1.012	.988
Livestock (TLU)	1.011	.989
Farm size	1.007	.993
Mean VIF	1.014	

Appendix Table 7. Contingency coefficient for categorical variables

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
(1) gender	1.000												
(2) educhh	0.086	1.000											
(3) off_farm	0.019	0.067	1.000										
(4) credit	0.033	0.049	0.003	1.000									
(5) exte	0.010	0.100	0.089	0.055	1.000								
(6) mseg	0.050	0.050	0.012	0.030	0.077	1.000							
(7) clm_inf	0.069	0.118	0.044	0.102	0.001	0.083	1.000						
(8) good__soil	0.116	0.086	0.019	0.016	0.038	0.070	0.041	1.000					
(9) moderate_soil	0.043	0.124	0.000	0.049	0.055	0.104	0.027	0.556	1.000				
(10) slope_flat	0.040	0.174	0.035	0.083	0.044	0.031	0.044	0.048	0.064	1.000			
(11) moderate_slope	0.077	0.052	0.024	0.082	0.068	0.012	0.064	0.024	0.017	0.533	1.000		
(12) erosion	0.048	0.148	0.054	0.057	0.153	0.031	0.056	0.099	0.013	0.001	0.044	1.000	
(13) clmt_shock	0.137	0.119	0.132	0.055	0.105	0.061	0.027	0.082	0.080	0.097	0.058	0.119	1.000

Appendix Table 8. Marginal effects estimate for the climate change adaptation strategies: multinomial logit selection model

Variables	$A_1S_1L_1$	$A_0S_1L_0$	$A_1S_0L_1$	$A_1S_1L_0$	$A_1S_0L_0$
lnagehh	-0.012*	0.031	-0.059	-0.036*	0.063**
	(0.06)	(0.057)	(0.066)	(0.082)	(0.084)
educhh	0.051	0.019	0.037	0.055	-0.104
	(0.027)	(0.021)	(0.023)	(0.033)	(0.035)
lnfam_siz	-0.026	0.033	-0.06**	0.036	0.028
	(0.041)	(0.029)	(0.028)	(0.037)	(0.036)
lnlivestock	0.229***	-0.042***	-0.088***	-0.054***	0.017
	(0.02)	(0.014)	(0.015)	(0.019)	(0.026)
lnfarm_size	0.041	-0.013	-0.01	0.044	-0.018
	(0.031)	(0.027)	(0.029)	(0.039)	(0.033)
credit	-0.042	-0.005	-0.013	-0.008	0.066
	(0.033)	(0.035)	(0.037)	(0.045)	(0.042)
lndis_mkt	-0.012	0.005	0.014	-0.013	0.013
	(0.015)	(0.017)	(0.019)	(0.024)	(0.019)
exte	0.023	-0.044	-0.028	0.034	0.01
	(0.036)	(0.035)	(0.038)	(0.047)	(0.042)
clm_inf	0.002	-0.001	-0.062	0.017	0.012
	(0.036)	(0.036)	(0.038)	(0.048)	(0.045)
good__soil	-0.087*	-0.06	0.055	0.095	-0.044
	(0.045)	(0.039)	(0.054)	(0.059)	(0.056)
moderate_soil	0.006	-0.129***	0.035	-0.013	0.003
	(0.041)	(0.048)	(0.056)	(0.064)	(0.056)
slope_flat	-0.162***	-0.065	-0.026	0.207	0.108*
	(0.035)	(0.04)	(0.046)	(0.06)	(0.06)
moderate_slope	-0.074*	-0.027	-0.008	0.041	0.075
	(0.043)	(0.04)	(0.047)	(0.071)	(0.064)
erosion	-0.048	0.036	-0.031	0.211***	-0.079*
	(0.032)	(0.033)	(0.034)	(0.043)	(0.043)
clmt_shock	-0.017	0.032	0.047**	-0.023	0.034
	(0.023)	(0.025)	(0.023)	(0.036)	(0.032)
gender	0.038	-0.054	-0.092***	0.019	0.063
	(0.037)	(0.04)	(0.036)	(0.054)	(0.053)
mseg	-0.082**	-0.013	0.036	0.072	-0.028
	(0.035)	(0.035)	(0.034)	(0.046)	(0.043)
lnclmt_perc	0.019	0.012	-0.046	0.027	0.077*
	(0.031)	(0.034)	(0.041)	(0.05)	(0.046)

Note: *, ** and *** indicate statistical significance at 10%, 5% and 1%, respectively; $A_0S_0L_0$ is the reference category; The steep slope and poor soil quality are considered as reference categories for slopes and soil fertility

Appendix Table 9. Estimation of the mean equations (dep. variable: log farm income)

Explanatory variables	$A_1S_1L_1$ Coef.	$A_1S_1L_1$ Std.Err.	$A_0S_1L_1$ Coef.	$A_0S_1L_1$ Std.Err.	$A_0S_0L_1$ Coef.	$A_0S_0L_1$ Std.Err.	$A_0S_1L_0$ Coef.	$A_0S_1L_0$ Std.Err.	$A_0S_0L_0$ Coef.	$A_0S_0L_0$ Std.Err.
Household characteristics										
Gender	0.22	0.61	-1.09***	0.23	0.21	0.71	-0.95	1.70	0.22	5.84
Age	0.00	0.66	7.11***	0.21	-0.14	0.86	-0.40	2.26	0.47	16.81
Education	-0.24	0.40	2.69***	0.29	0.20	0.64	0.03	1.05	0.55	18.63
Family size	-0.09	0.38	-0.12	0.23	-0.48	0.69	0.46	1.33	0.45	2.91
Resource constraints and market access										
Livestock	-0.22	1.03	-4.53***	0.17	-0.36	0.78	-0.56	1.09	0.22	9.64
Farm size	0.31	0.64	-0.16	0.26	-0.04	0.61	-0.45	1.43	0.52	6.49
Off farm	-0.23	0.73	-0.11	0.32	-0.32	0.58	0.53	1.23	0.40	4.41
Credit	0.03	0.68	-2.38	0.23	-0.13	0.70	0.31	1.07	-0.87	5.18
Distance	0.23	0.38	-0.44*	0.17	-0.09	0.31	0.20	0.79	-0.29	0.95
Institutional factors										
Extension	0.04	0.34	-2.98***	0.31	0.01	0.86	-0.57	1.21	0.81	3.81
Membership	0.26	0.98	-1.80***	0.24	0.50	0.72	-0.86	1.38	0.29	7.13
Climate inf.	0.32	0.36	1.23***	0.37	-0.05	0.58	-0.43	1.27	0.01	11.74
Farm plot characteristics										
Good soil	-0.08	0.50	-0.71**	0.26	0.51	0.76	-0.93	2.04	-0.52	5.42
Moderate soil	0.10	0.45	-4.51***	0.24	0.43	0.74	-1.81	1.69	-0.72	25.83
Slope flat	0.41	1.27	0.53	0.36	0.55	0.84	-1.07	1.97	1.45	7.48
Moderate slope	-0.17	0.66	3.48	0.40	0.21	0.81	0.06	1.45	0.83	8.03
erosion	-0.66	0.54	3.19	0.28	-0.06	0.74	-0.46	1.97	0.24	23.01
Climate change perception and shock										
Climate shk	0.12	0.44	-3.56	0.26	-0.30	0.56	0.80	1.05	0.32	7.71
Constant	10.62**	3.26	-17.69**	1.19	12.13***	4.03	8.99	9.36	8.07	68.38
Joint significance of instruments	F (1,38) = 0.39		F (1,5) = 0.79		F (1,11) = 1.10		F (1,17) = 0.05		F (1,18) = 0.69	

Appendix Table 9. Continued

Explanatory variables	$A_1S_0L_1$ Coef.	$A_1S_0L_1$ Std.Err.	$A_1S_1L_0$ Coef.	$A_1S_1L_0$ Std.Err.	$A_1S_0L_0$ Coef.	$A_1S_0L_0$ Std.Err.
Household characteristics						
Gender	-0.01	0.87	0.12	0.23	-0.18	0.37
Age	-0.08	1.30	-0.04	0.27	0.28	0.47
Education	0.10	0.62	-0.14	0.15	-0.16	0.35
Family size	0.13	0.69	0.20	0.15	-0.09	0.24
Resource constraints and market access						
Livestock	-0.09	0.57	0.18	0.19	0.21	0.40
Farm size	-0.12	0.59	-0.11	0.15	-0.06	0.26
Off farm	0.06	0.84	0.06	0.17	0.44	0.36
Credit	-0.29	0.72	0.10	0.16	-0.13	0.24
Distance	-0.13	0.36	-0.03	0.07	0.03	0.16
Institutional factors						
Extension	0.15	0.63	-0.09	0.17	-0.13	0.29
Membership	-0.03	0.57	-0.11	0.15	-0.09	0.38
Climate inf.	-0.15	0.75	0.12	0.15	0.07	0.30
Farm plot characteristics						
Good soil	0.14	1.00	-0.10	0.25	-0.20	0.45
Moderate soil	0.28	1.11	0.20	0.29	0.00	0.48
Slope flat	0.19	1.07	-0.29	0.26	-0.34	0.55
Moderate slope	0.45	0.85	-0.20	0.25	-0.22	0.53
erosion	-0.06	1.09	0.16	0.33	-0.16	0.58
Climate change perception and shock						
Climate shk	-0.32	0.59	-0.01	0.14	0.27	0.31
Constant	10.98**	5.49	10.46**	1.14	9.36***	2.80
Joint significance of instruments	$F(1,27) = 0.54$		$F(1,67) = 0.12$		$F(1,47) = 0.15$	

Note: SE is bootstrapped standard error, *, ** and *** indicate statistical significance at 10%, 5% and 1%, respectively.

Appendix Table 9. Continued

Ancillary	$A_1S_1L_1$	$A_0S_1L_1$	$A_0S_0L_1$	$A_0S_1L_0$	$A_0S_0L_0$	$A_1S_0L_1$	$A_1S_1L_0$	$A_1S_0L_0$
Sigma2	9.23	580.51***	11.63	11.07	13.98***	5.70	2.47*	5.39
	(56.48)	(0.44)	(17.36)	(205.3)	(62974.5)	(47.40)	(1.42)	(5.78)
rho1		-0.07	0.13	-0.04	-0.41	0.45	0.16	0.20
		(0.83)	(0.62)	(0.68)	(0.77)	(0.83)	(0.48)	(0.47)
rho2	-0.74		-0.08	0.21	0.55	0.38	-0.12	-1.37*
	(1.21)		(0.64)	(0.72)	(0.65)	(0.62)	(0.62)	(0.81)
rho3	1.32	0.00		0.13	0.97	-1.39**	-0.12	0.95
	(0.74)	(0.47)		(0.67)	(0.72)	(0.73)	(0.64)	(0.76)
rho4	-0.81*	1.18	-0.79		-0.36	-0.01	1.16*	0.71
	(0.84)	(0.75)	(0.62)		(0.73)	(0.70)	(0.70)	(0.76)
rho5	0.30	0.12	0.49	-0.52		0.76	0.22*	0.20
	(0.65)	(0.65)	(0.86)	(0.72)		(0.74)	(0.65)	(0.70)
rho6	-0.54	-0.03	0.88	0.67	-1.08		-1.22	-0.08
	(0.76)	(0.52)	(0.62)	(0.69)	(0.72)		()0.69	(0.75)
rho7	-0.22	-0.12	0.40	-1.21**	0.39	0.30		-0.61
	(0.69)	(1.00)	(0.76)	(0.64)	(0.77)	(0.69)		(0.71)
rho8	0.68	-1.20**	-0.90	0.24	0.17	-0.43	0.03	
	(0.64)	(0.53)	(0.64)	(0.72)	(0.59)	(0.65)	(0.72)	
Number of observations				390				

Note: SE is bootstrapped standard error, *, ** and *** indicate statistical significance at 10%, 5% and 1%, respectively.

Appendix Table 10. Estimation of the skewness equations (dep. variable: farm income skewness).

Variables	$A_1S_1L_1$		$A_0S_1L_1$		$A_0S_0L_1$		$A_0S_1L_0$	
	Coef.	St.Err	Coef.	St.Err	Coef.	St.Err	Coef.	St.Err
Age	0.163	0.253	0.015	0.057	-0.211	1.162	-0.210	1.210
Education	0.021	0.110	0.009	0.030	-0.046	0.563	0.033	1.579
Family size	-0.098	0.093	-0.019	0.024	-0.344	0.764	0.049	0.620
Livestock	0.028	0.179	-0.010	0.030	-0.335	0.524	0.019	0.504
Farm size	0.050	0.090	0.039	0.037	-0.168	0.708	0.070	0.361
Off farm	-0.122	0.117	-0.034	0.046	-0.337	0.648	-0.086	1.745
Credit	-0.019	0.145	-0.038	0.031	0.231	0.662	0.131	0.490
Extension	0.074	0.098	0.031	0.042	-0.416	0.799	0.042	0.921
Good soil	0.074	0.098	0.031	0.042	-0.416	0.799	0.042	0.921
Moderate soil	0.132	0.168	0.070	0.052	0.267	0.792	-0.015	1.663
Slope flat	0.288	0.186	0.023	0.036	-0.016	1.171	-0.098	1.519
Moderate slope	-0.041	0.190	0.013	0.044	0.390	0.834	0.300	1.594
erosion	0.030	0.158	0.002	0.039	0.277	1.018	0.086	0.517
Climate perception	0.016	0.119	0.064	0.039	0.068	1.383	0.141	2.277
Climate shock	-0.118	0.137	-0.048	0.037	0.189	0.779	0.213	1.328
Constant	-0.121	0.088	-0.015	0.028	-0.087	0.793	-0.042	0.404
Significance of Instrument	F (4,38) = 0.6		F (4,5) = 6.84		F (4,11) = 0.75		F (4,17) = 0.42	
Ancillary								
Sigma2	1.902	2.537	0.048	0.015	5.322	39.830	0.773	772.877
rho1			0.477	0.809	0.017	0.733	-0.399	0.566
rho2	0.990	1.153			-0.504	0.547	-0.256	0.744
rho3	0.403	0.664	0.514	0.431			-0.760	0.847
rho4	-1.724	0.849	-0.604	0.770	-0.376	0.644		
rho5	0.544	0.646	-0.372	0.638	0.384	0.668	-0.381	0.741
rho6	-0.064	0.884	-0.012	0.537	1.254	0.705	0.289	0.616
rho7	0.099	0.602	0.831	0.950	0.245	0.731	1.118	0.608
rho8	-0.316	0.538	-1.046	0.615	-0.714	0.649	0.393	0.694
Number of observations				390				

Notes: $A_0S_0L_0$ is the reference category. Standard errors were bootstrapped with 100 replications.

Appendix Table 10. Continued

Variables	$A_0S_0L_0$		$A_1S_0L_1$		$A_1S_1L_0$		$A_1S_0L_0$	
	Coef.	St.Err	Coef.	St.Err	Coef.	St.Err	Coef.	St.Err
Age	0.665	6.341	0.000	0.282	0.011	0.107	0.100	0.162
Education	0.082	2.870	0.054	0.128	-0.054	0.050	-0.119	0.138
Family size	0.360	1.766	-0.016	0.838	0.059	0.051	-0.071	0.078
Livestock	0.476	2.257	-0.035	0.143	-0.012	0.056	0.131	0.117
Farm size	0.476	1.263	-0.063	0.484	-0.072	0.059	0.008	0.093
Off farm	-0.002	2.756	-0.027	0.377	-0.019	0.063	0.078	0.125
Credit	-0.262	1.273	-0.097	0.197	0.038	0.051	0.036	0.101
Extension	0.522	1.584	0.078	0.166	-0.049	0.049	0.029	0.112
Good soil	0.522	1.584	0.078	0.166	-0.049	0.049	0.029	0.112
Moderate soil	-0.850	6.929	0.133	0.268	0.047	0.085	-0.042	0.159
Slope flat	-0.461	8.127	0.150	0.389	0.107	0.100	-0.044	0.154
Moderate slope	1.200	2.921	0.032	0.468	-0.069	0.087	0.142	0.227
erosion	0.871	2.136	0.123	0.400	-0.069	0.089	0.127	0.219
Climate perception	-0.615	6.172	-0.083	0.220	0.048	0.104	0.044	0.187
Climate shock	0.507	3.255	-0.091	0.178	0.076	0.085	0.141	0.168
Constant	-1.979	27.237	-0.104	0.484	-0.038	0.048	0.017	0.108
Significance of Instrument	F (4,18) = 2.37		F (4,27) = 0.92		F (4,67) = 0.55		F (4,47) = 0.18	
Ancillary								
Sigma2	20.225	2730.856	0.417	108.958	0.241	0.242	0.274	0.922
rho1	-0.380	0.765	0.586	0.831	-0.241	0.564	0.930	0.444
rho2	0.127	0.681	0.437	0.766	0.464	0.617	-1.474	0.856
rho3	0.685	0.727	-0.949	0.751	-0.493	0.624	-0.066	0.793
rho4	-0.459	0.784	-0.619	0.738	1.061	0.739	-0.124	0.778
rho5			0.936	0.595	0.193	0.621	-0.328	0.660
rho6	-0.277	0.559			-1.066	0.622	0.378	0.777
rho7	-0.593	0.667	0.241	0.618			0.435	0.656
rho8	1.126	0.709	-0.623	0.621	0.250	0.618		
Number of observations				390				

Notes: $A_0S_0L_0$ is the reference category. Standard errors were bootstrapped with 100 replications.

Appendix Table 11. Three-step Feasible Generalized Least Squares result for determinant of vulnerability to food insecurity.

	Log food consumption expenditure			Variance of food consumption expenditure		
Variables	Coef.	Robust Std. Err.	*t*	Coef.	Robust Std. Err.	*t*
Gender	0.112	0.079	1.43	0.091	0.081	1.12
Age	0.108	0.125	0.87	0.059	0.120	0.5
Educ	0.111*	0.058	1.9	0.128*	0.072	1.79
Livestock	0.072	0.044	1.63	-0.080	0.052	-1.53
Extension	-0.026	0.073	-0.35	-0.193**	0.079	-2.44
Membership	-0.058	0.072	-0.8	-0.061	0.079	-0.77
Good soil	0.144	0.101	1.43	-0.036	0.107	-0.33
Off farm	-0.006	0.069	-0.09	-0.079	0.070	-1.13
Credit	0.079	0.071	1.12	-0.183**	0.078	-2.36
Moderate soil	0.207**	0.107	1.94	-0.090	0.107	-0.84
Slope flat	0.054	0.074	0.74	0.001	0.075	0.02
Erosion	-0.075	0.073	-1.03	0.008	0.077	0.11
Climate shock	0.079	0.052	1.54	0.105*	0.061	1.71
Adult equivalence	-0.089***	0.022	-3.98	-0.011	0.023	-0.47
_cons	9.056	0.469	19.32	0.415	0.449	0.92
F (14,374) =2.83					F (14,374) = 2.69	
Prob >F = 0.0005					Prob > F= 0.0009	
R- squared=0.098					R- squared= 0.1417	
Root MSE=0.673					Root MSE=0.688	
Number of Observations		390				

***, ** and * significant at the 1, 5 and 10% probability levels, respectively

Appendix Table 12. Mixed multinomial logit model: determinants of multiple adaptation strategies.

Variables	$A_1S_1L_1$		$A_0S_1L_1$		$A_0S_0L_1$		$A_0S_1L_0$		$A_1S_0L_1$		$A_1S_1L_0$		$A_1S_0L_0$	
	Coef.	SE.	Coef.	SE	Coef.	SE	Coef.	SE	Coef.	SE	Coef.	SE	Coef.	SE
Gender	0.707	0.748	-0.211	0.792	-0.524	0.705	-1.080	0.708	-1.204*	0.658	-0.151	0.616	0.298	0.646
Age	-0.130	1.154	2.218*	1.201	0.397	1.097	0.456	1.111	-0.522	1.020	-0.070	0.919	0.647	0.957
Educ	1.074**	0.487	0.839*	0.476	0.946**	0.457	0.676	0.461	0.786*	0.426	0.824**	0.390	-0.266	0.427
Livestock	3.927***	0.507	-0.312	0.325	0.651*	0.343	0.301	0.322	-0.480*	0.283	0.567**	0.273	1.142***	0.298
Extension	0.637	0.606	1.025	0.660	0.774	0.604	-0.169	0.592	0.035	0.550	0.489	0.499	0.442	0.516
Membership	-1.073*	0.616	0.142	0.631	0.708	0.583	-0.058	0.594	0.345	0.542	0.438	0.489	-0.273	0.512
Good soil	-1.693**	0.873	1.070	0.953	-0.395	0.829	-1.144	0.775	0.312	0.815	-0.098	0.723	-0.865	0.754
Off farm	0.934	0.595	-0.281	0.658	0.664	0.587	1.386**	0.584	0.031	0.558	0.653	0.495	0.295	0.511
Credit	-0.303	0.590	-0.501	0.620	-0.368	0.576	-0.051	0.572	0.154	0.536	0.110	0.481	0.517	0.498
Moderate soil	-0.945	0.884	-0.617	1.010	-1.278	0.877	-2.545***	0.882	-0.625	0.844	-1.127	0.749	-0.833	0.765
Slope flat	-1.164*	0.620	0.351	0.626	0.652	0.589	-0.181	0.605	0.500	0.555	1.514***	0.501	0.722	0.515
Erosion	0.346	0.630	1.201*	0.657	0.732	0.610	1.371**	0.607	0.719	0.574	2.040***	0.526	0.231	0.547
Climate shk	0.590	0.455	0.651	0.476	1.045**	0.441	1.158***	0.442	1.399***	0.423	0.670*	0.385	0.977**	0.396
Adult eqv.	-0.168	0.165	-0.151	0.174	-0.183	0.162	-0.507***	0.168	-0.104	0.151	-0.220	0.137	-0.331**	0.141
Distance	-0.189	0.297	-0.095	0.309	0.195	0.295	0.108	0.293	0.139	0.271	-0.149	0.241	0.094	0.254
Climate info	-0.390	0.613	-0.818	0.656	-0.443	0.595	-0.788	0.595	-1.114*	0.580	-0.428	0.497	-0.386	0.509
Climate Perc.	1.227**	0.626	-0.466	0.602	-0.024	0.568	1.116*	0.648	0.245	0.572	0.924**	0.508	1.495***	0.580
_cons	-3.011	4.432	-9.908**	4.798	-3.672	4.249	0.064	4.235	1.279	3.913	-0.478	3.532	-2.228	3.700
Wald $\chi2$ (17)							71.82***							
Number of observations							390							

Notes: *, ** and *** indicate statistical significance at 10%, 5% and 1%, respectively; SE is robust standard errors; $A_0S_0L_0$ is the reference category.

Appendix Table 13. Second Stage Estimation of the Multinomial Endogenous Treatment Effect Model

Variables	$A_1S_1L_1$		$A_0S_1L_1$		$A_0S_0L_1$		$A_0S_1L_0$		$A_1S_0L_1$		$A_1S_1L_0$		$A_1S_0L_0$	
	Coef.	SE.	Coef.	SE	Coef.	SE	Coef.	SE	Coef.	SE	Coef.	SE	Coef.	SE
Gender	0.375	0.733	-0.339	0.778	-0.597	0.696	-1.124	0.695	-1.188*	0.643	-0.248	0.595	0.236	0.637
Age	-0.312	1.175	2.647**	1.212	0.318	1.085	0.625	1.149	-0.628	1.001	-0.115	0.912	0.832	0.968
Educ	1.136**	0.484	1.006**	0.479	1.129**	0.452	0.817*	0.462	0.929**	0.417	0.854***	0.384	-0.172	0.420
Livestock	3.820***	0.503	-0.377	0.317	0.655*	0.338	0.330	0.312	-0.475*	0.276	0.509	0.266	1.102***	0.294
Extension	0.661	0.600	1.150*	0.649	0.835	0.598	-0.257	0.589	0.118	0.540	0.412	0.488	0.454	0.507
Membership	-0.961	0.607	0.047	0.629	0.450	0.574	-0.167	0.587	0.380	0.533	0.462	0.473	-0.425	0.507
Good soil	-1.644*	0.879	0.742	0.927	-0.598	0.825	-1.210	0.770	0.307	0.803	-0.053	0.707	-1.093	0.739
Off farm	1.080*	0.588	-0.358	0.654	0.680	0.576	1.321**	0.579	0.027	0.540	0.773	0.482	0.214	0.503
Credit	-0.231	0.584	-0.507	0.618	-0.249	0.560	-0.125	0.563	0.208	0.520	0.048	0.464	0.525	0.490
Moderate soil	-0.978	0.890	-0.997	0.984	-1.588*	0.874	-2.496***	0.873	-0.686	0.832	-1.159	0.729	-1.087	0.753
Slope flat	-1.095*	0.614	0.183	0.621	0.781	0.580	-0.347	0.600	0.640	0.548	1.397***	0.487	0.896*	0.511
Erosion	0.500	0.623	1.285**	0.655	0.797	0.598	1.409**	0.605	0.645	0.562	2.016***	0.512	0.244	0.538
Climate shk	0.646	0.458	0.746	0.467	1.034**	0.441	1.073**	0.444	1.394***	0.418	0.655	0.379	0.866	0.398
Adult eqv.	-0.190	0.163	-0.159	0.173	-0.188	0.161	-0.508***	0.170	-0.124	0.150	-0.227*	0.134	-0.344**	0.138
Distance	-0.226	0.289	-0.001	0.305	0.263	0.287	0.058	0.288	0.264	0.267	-0.158	0.231	0.175	0.247
Climate info	-0.365	0.612	-0.758	0.641	-0.339	0.583	-0.627	0.585	-1.203**	0.566	-0.346	0.483	-0.138	0.504
Climate Perc.	0.927	0.606	-0.500	0.581	-0.021	0.558	1.133*	0.635	0.375	0.545	0.897*	0.485	1.467***	0.568
_cons	-2.095	4.503	-11.52**	4.883	-3.498	4.212	-0.250	4.331	1.233	3.842	0.024	3.498	-2.890	3.748
Joint significance of instruments	F (3,40) = 0.73		F (3,7) = 0.97		F (3,13) = 0.91		F (3,19) = 0.22		F (3,29) = 0.17		F (3,69) = 0.03		F (3,49) = 0.58	
Number of observations			390											

Notes: $A_0S_0L_0$ is the reference category. *, ** and *** indicate statistical significance at 10%, 5% and 1%, respectively; Robust standard errors

Appendix Table 14. Risk premium R and its decomposition by quantiles

	Lower Case Scenarios (b=1)							
	Quantile 1		Quantile 2		Quantile 3		Quantile 4	
Choices	Variance	Skewness	Variance	Skewness	Variance	Skewness	Variance	Skewness
$A_1S_1L_1$	5.76	4.89	0.59	0.16	0.04	(0.00)	10.44	(11.84)
$A_0S_1L_1$	2.20	1.19	0.24	0.04	0.10	(0.01)	2.32	(1.28)
$A_0S_0L_1$	4.82	3.61	0.58	0.15	0.07	(0.00)	2.17	(1.13)
$A_0S_1L_0$	3.85	2.55	0.62	0.17	0.17	(0.02)	8.57	(8.76)
$A_0S_0L_0$	7.37	6.80	0.55	0.14	0.19	(0.03)	2.59	(1.52)
$A_1S_0L_1$	3.79	2.58	0.33	0.07	0.12	(0.01)	9.77	(10.61)
$A_1S_1L_0$	4.17	2.92	0.58	0.16	0.04	(0.00)	8.43	(8.52)
$A_1S_0L_0$	6.59	5.78	0.37	0.08	0.14	(0.02)	6.25	(5.46)
	Moderate Case Scenarios (b=1)							
$A_1S_1L_1$	11.51	14.66	1.19	0.48	0.08	(0.01)	4.64	(3.83)
$A_0S_1L_1$	4.41	3.56	0.47	0.12	0.19	(0.02)	4.64	(3.83)
$A_0S_0L_1$	9.64	10.83	1.16	0.46	0.14	(0.01)	4.34	(3.39)
$A_0S_1L_0$	7.69	7.64	1.24	0.52	0.34	(0.07)	17.14	(26.28)
$A_0S_0L_0$	14.75	20.41	1.10	0.43	0.37	(0.08)	5.18	(4.57)
$A_1S_0L_1$	7.58	7.73	0.65	0.20	0.25	(0.04)	19.53	(31.83)
$A_1S_1L_0$	8.33	8.75	1.15	0.47	0.08	(0.01)	16.86	(25.57)
$A_1S_0L_0$	13.17	17.34	0.74	0.24	0.29	(0.05)	12.50	(16.39)

Note: Both variances and skewness measures are rescaled by dividing by1,000

Appendix Table 15. Coefficients of multinomial logit model: The dependent variable quantile groups

Variables	Quantile 1		Quantile 3		Quantile 4	
	Coef.	SE.	Coef.	SE	Coef.	SE
Age	0.269	0.623	-0.517	0.583	0.214	0.586
Educ	-0.102	0.234	0.267	0.234	-0.166	0.226
Family Size	-0.056	0.258	-0.099	0.263	0.129	0.257
Livestock	-0.183	0.152	-0.102	0.158	0.114	0.155
Farm Size	-0.440*	0.249	-0.320	0.242	-0.179	0.254
Off farm	-0.064	0.318	0.292	0.312	-0.180	0.304
Credit	0.567*	0.314	-0.105	0.314	0.190	0.301
Extension	-0.540*	0.317	-0.310	0.332	-0.296	0.318
Good soil	-0.545	0.420	-0.539	0.419	-0.262	0.414
Moderate soil	-0.391	0.450	-0.376	0.447	0.216	0.433
Slope flat	-1.178***	0.431	-0.405	0.398	-0.343	0.406
Moderate slope	-0.320	0.440	-0.434	0.435	-0.377	0.441
Erosion	-0.632**	0.308	-0.033	0.315	-0.451	0.311
Climate Perception	-0.300	0.325	-0.301	0.327	-0.372	0.353
Climate Shock	-0.539***	0.252	-0.26	0.233	0.124	0.211
Gender	0.538	0.364	0.897*	0.375	0.603*	0.360
Membership	0.075	0.322	0.133	0.316	0.145	0.313
Climate info	0.321	0.324	0.005	0.327	0.045	0.318
_cons	-0.078	0.157	-0.240	0.157	-0.227	0.153

Notes: *, ** and *** indicate statistical significance at 10%, 5% and 1%, respectively; SE is robust standard errors; 2nd quantile group is the reference category.

Appendix Table 16. A falsification test of instruments.

Outcome variable	Choices	F-statistics	P-value
Farm income	$A_1S_1L_1$	0.14	0.9335
	$A_0S_1L_0$	0.14	0.9328
	$A_0S_0L_0$	0.87	0.4748
	$A_1S_0L_1$	2.15	0.1168
	$A_1S_1L_0$	0.42	0.7403
	$A_1S_0L_0$	0.12	0.9459
Downside risk exposure (skewness)	$A_1S_1L_1$	0.67	0.5742
	$A_0S_1L_0$	0.49	0.6959
	$A_0S_0L_0$	1.25	0.3195
	$A_1S_0L_1$	1.01	0.4049
	$A_1S_1L_0$	0.47	0.7069
	$A_1S_0L_0$	0.10	0.9577

7.2. Survey Questionnaire

Appendix Table 8. Household survey

Household survey

My name is Andualem Begashaw. I am doing a Ph.D. degree in Agricultural Economics at Haramaya University. The title of the Ph.D. study is "Adaptation of Climate Change and Variability and its Impact on Welfare of Smallholder Farmers in Bench Maji Zone, Southwest Ethiopia Peoples' Regional State, Ethiopia". The purpose of the study is to empirically assess and analyze the impact of different adaptation strategies on farm household welfare in Bench Maji zone, southwest Ethiopia.

My contact number is +251 913 651 246

Before we begin the interview, I want to make sure you understand the following information about the study:

- Your participation is entirely voluntary. You may refuse to take part in the interview, and you may stop at any time if you do not want to continue.
- The average amount of time for this interview is about 45-60 minutes.
- You have the right to ask questions at any point before the interview, during the interview, or after the interview is completed.
- All information collected for this study will be kept strictly confidential. While the data collected will be used for research purposes, information that could identify you or your household will never be publicly released in any research report or publication.

Thank you for your patience and cooperation.

A. Area And Household Identifications

Household Identification Number [ ] [ ] [ ]

Date of interview: / / 2014 E.C

Name of enumerator ……………………………………….

Signature ………………………………

District Name ……………………. Kebele Name……………………. Locality Name……………….

Traditional agroecological Zone [1] Dega [2] Weyna Dega [3] Kolla

B. Basic Information about the Respondent and Her/His Household (Respondent should be the decision maker of the household)

1. Name of Household head:	2. Sex [1] Male [2] Female	3. Age (Years)	4. Marital Status [1] Married [2] Never Married [3] Married [4] Separated [5] Divorced [6] Widowed	5. Highest completed level of education ?	6. Number of years the family of the household members is living in the village:

7. What is the composition of age?

Age group		0-1	1-2	2-3	3-5	5-7	7-10	10-12	12-14	14-16	16-18	18-30	30-60	60 and above
Sex	M													
	F													

C. Land Holding and Tenure Characteristics

8. Does Your household have land for agricultural production and other activities? [1] Yes [2] No

9. How did you obtain your land / farm? [1] Owned [2] Purchased [3] Rented in [4] Borrowed [5] Other (specify)

10. What is the total land owned by your household currently (In Tsimade or Hectare) ....

11. What type of farming did the Hh has? [1] Crop production only [2] Livestock rearing only [3] Both

12. What is the main purpose of your household involvement in agriculture production? [1] Produce for own family consumption only (subsistence) [2] Produce and sell in the market (commercial) [3] Produce for the family and sell the surplus quantity (semi commercial)

13. How many times does your Hh usually harvest Temporary Crop Per Year?..................

14.Plot slope [1] Flat [2] Gentle [3] Steeper

15. How far is your house from the following resources?

i. Distance from where you buy your agricultural inputs (e.g. hoes, seeds, fertilizers, etc.) (farm to market in KM or time it takes) ______.
ii. Market where you sell agricultural products (KM or time it takes) _______.
iii. Distance from home to farm (KM or time it takes) ______.

16. How is the fertility of the soil of your farm in general? [1] Very fertile [2] Medium [3] Low

17. What are the physical characteristics of your farm, in terms of its exposure to erosion?

[1] Susceptible to erosion [2] Moderately susceptible to erosion [3] Not susceptible at all

D. Extension Services and Information Access

18. During the last 12 months, have you received agricultural advice (extension) about the following topics?

Type of advice	Have you received any advice in the last 12 months? [1] Yes [2] No (skip to Next Type)	How many visits did you receive in the last 12 months?	Did you follow the advice that you received? [1]Yes [2] No
Improved varieties			
Seed recommendations			
Nutrient deficiencies (type of soil) in plots			
Compost fertilizer management and application			
Chemical fertilizer application			
Water / irrigation management			

Type of advice	Have you received any advice in the last 12 months? [1] Yes [2] No (skip to Next Type)	How many visits did you receive in the last 12 months?	Did you follow the advice that you received? [1]Yes [2] No
Disease prevention / treatment for crops			
Pest prevention / treatment for crops			
Info of where to sell output			
Advice on output prices			
Advice on input prices			
Animal health services			
Animal feeding / care and breeding			
Soil and water conservation practices			
Disaster risk reduction measure			
Access to credit (microfinance / savings group)			
Others (specify)			

19. Access to credit last season: [1] Yes [2] No

20. Amount of credit received last season: ……………… Birr.

21. Do you have access to early warning information on Climate variability? [1] Yes [0] No

E. Crop Production in 2013 E.C. Crop Season

22. Details of Crop Production during Last Year

Crops cultivated during the last 12 months	**Amount produced (Qt)**	**Amount used for Consumption (Qt)**	**Amount used for sale (Qt)**	**Unit price**	**Total Revenue from sales**
Teff					
Barley					
Wheat					
Maize					
Sorghum					
Sesame					

Crops cultivated during the last 12 months	Amount produced (Qt)	Amount used for Consumption (Qt)	Amount used for sale (Qt)	Unit price	Total Revenue from sales
Tomatoes					
Onion					
Garlic					
Carrot					
Beetroot					
peppers					
Ethiopian cabbage					
Head cabbage					
Yam					
Cassava					
Potato					
Taro/ Godere					
Sweet Potato					
Banana					
Orange					
Papaya					
Mango					
Avocado					
Coffee					
Enset					
Sugar cane					
Horse beans					
Lentils					
Haricot beans					
Field peas					
Chat					

23. Farm Input Use

Did you apply Chemical fertilizer in your plot?	Improved seed (kg)		Fertilizer (kg)	Pesticide (lit)		Herbicides (kg)			Anti-disease (kg)	
[1] Yes [0] No	Qty	Birr	Qty	Birr	Qty	Birr	Qty	Birr	Qty	Birr

F. Livestock Ownership and Income over the Past 12 Months

24. Does the household own livestock or animals? [1] Yes [2] No	25. If 'Yes', Types of livestock	26. How much livestock does the household currently own?	27. Income from Animals (2013 E.C)			28. Associated costs
			Number of Animal sold	Unit price (Birr)	Total income (Birr)	
	Calf					
	Weaned calf					
	Heifer					
	Cow					
	Oxen					
	Horse					
	Donkey (adult)					
	Donkey (young)					
	Mule (adult)					
	Mule (young)					
	Sheep (adult)					
	Sheep (young)					
	Goat (adult)					
	Goat (young)					

G. Income from Products and by-Products of Livestock in 2013 E.C

29. Have you sold animal/ products last year? [1] Yes [2] No	Name of Animals	Products and By-products	30. Sold			
			Unit	Unit Price	Quantity	Total Income
	Cows	Milk	Lt.			
		Butter	Kg			
	Hen	Chickens	Number			
		Layers	Number			
		Cocks	Number			
		Eggs	Number			
	Animal Labor Rent	Oxen	oxe/day			
		Donkey	donkey/day			
		Mule	mule/day			
		Horse	horse/day			
	Bee Hive	Honey	Kg			
		Wax	Kg			
	Goats and sheep	Hide and Skin	Birr			

H. Off-Farm Income

31**.** Did you engage in off-farm income generating activities in 2013 E.C**?** [1] Yes [2] No

32. If your answer is yes, in which source did you get additional income in 2012 E.C?

Off-farm Activity	How many days Per month	Daily Earning	Monthly earning
Petty trade			
Pottery			
Weaving			
Leather making			
Selling of fire wood			
Agricultural Labor: On other's farm			
Transportation by "Gary"			

I. Social Capital

34. Are you and any from your household is a member of any farmer's group or cooperative or in any other groups/committees active e.g. women's group, savings group, mothers' group)?	**[1]yes [2] No**	**35. [If yes]** How will you rate your involvement in the group's activities [1] Inactive [2] Sometimes [3]Always	36. Does a member of your household hold a specific position in this group? [1] Yes [2] No [3] I don't know
Idir			
Equib			
Farming cooperatives/unions			
Trade unions			
Religious associations			
Females' associations			
School council			
Other please specify			

J. Perception of Farmers on Climate Change and Variability

37. Have you observed any long-term changes in the mean of climate variables (particularly temperature and rainfall) over the last 15 years
[1] Yes
[2] No If yes, indicate (√) what have been the changes

Long term changes in the mean of climate variables	Highest increased	Increase	Stayed the same	Highest decrease	Decrease
Temperature patterns of your locality during summer season					
Temperature patterns of your locality during winter season					
Length of summer season in your locality					
Length of winter season in your locality					
Precipitation (rainfall/snowfall) of your locality					
Frequency (and intensity) of heavy rainfall in your locality					
Unpredictability of weather/ Others (specify)					

K. CLIMATE RELATED SHOKS

38. Do you think there is negative impact of the above changes in agriculture production? [1] Yes [2] No

Please fill the following if you are experienced with it.						
Sr. No	Have you experienced with any of the following shocks?	[1] Yes [2] No	If Yes, how often? (in past decade)	What is their direction of change? [1] Decreased [2] Increased [3] Unchanged	In which period did you start noticing the stated phenomena? [1] Past 2 years [2] Past 5 years [3] Past 10 years [4] Past 20 years	*How severe was the impact for your household? [1] No impact [2] Low impact [3] Medium impact [4] High impact
1	Increase in intensity and duration of drought					
2	Floods					
3	Landslides					
4	Crop pests and diseases					
5	Weeds pressure					
6	Death of livestock due to shortage of fodder and water					
7	Food shortage /insecurity					
8	Land degradation/ Decreasing soil fertility					
9	Loss of pasture land and vegetation					
10	Drying up of streams					
11	Others (specify)					

*Severity of the risks to shocks perceived by households is defined low if no major harm was done to the household, medium if manageable damage occurred and high if loss of land or life threating events occurred.

L. Climate Change Adaptation Strategies Used by The Farmers

39. Have you done anything to deal with climate change and variability (shifts in climate variables)?

[1] Yes [2] No

40. If Yes to #39, what are some of the adaptation measures have you made to these long term shifts in temperature and rainfall?	Response [1] Yes [2] No	If yes		41. Reasons for not taking adaptation (Code)
		Since how many years?	In how much area? (%)	
Planting drought-resistant crops/varieties				
Grow diverse varieties/crop diversifications				
Planting disease/pest-tolerant varieties				
Early planting				
Late planting				
Intercropping/mixed cropping				
Fallowing				
Mulching				
Implementation of Soil and Water Conservation (Stone band, Soil band, Bench terracing)				
Use of pesticides and insecticides				
Improve chemical fertilizer use				
Keep more livestock, instead of crops				
Keep more crops, instead of livestock				
Agroforestry Practice				
Non-timber forest product commercialization				
temporal migration to urban areas or abroad				
temporal migration to other rural areas				
Do more off-farm/non-farm work, instead of farming				
Charcoal or timber sales				
Small scale Irrigation				
Do nothing				
Other adaptations techniques				

M. Food Security

42. Could you please provide the following information about all the foods that you bought with money, ate from your farm or garden, or got from other people, such as friends, someone a family member worked for, or the government?

Cereals	Since last [day of week today] did you or others in your household acquire any [Name of food item]? [1] Yes [2] No	How much did you eat from your own production?		How much money would you spend if you bought it?	How much did you buy?		How much money did you spend?	How much did you receive from other people?		How much money would you spend if you bought it?
		Unit	Qty		Unit	Qty		Unit	Qty	
Maize, grain										
Maize, flour										
sorghum										
wheat										
Rice, local, paddy										
Millet										
Bread										
Buns										
Spaghetti or macaroni										
Enjera										
Other										

Roots, tubers, and plantains	Since last [day of week today] did you or others in your household acquire any [Name of food item]? [1] Yes [2] No	How much did you eat from your own production?		How much money would you spend if you bought it?	How much did you buy?		How much money did you spend?	How much did you receive from other people?		How much money would you spend if you bought it?
		Unit	Qty		Unit	Qty		Unit	Qty	
potato										
yam										
cassava										
sweet potato										
taro										
other tubers										

Pulses, nuts, and seeds	Since last [day of week today] did you or others in your household acquire any [name of food item]? [1] Yes [2] No	How much did you eat from your own production?		How much money would you spend if you bought it?	How much did you buy?		How much money did you spend?	How much did you receive from other people?		How much money would you spend if you bought it?
		Unit	Qty		Unit	Qty		Unit	Qty	
Beans										
Cowpeas										
Peanuts										
Lentils										
Nut										
Soy										
Pigeon pea										
Other nuts										

Vegetables	Since last [day of week today] did you or others in your household acquire any [name of food item]? [1] Yes [2] No	How much did you eat from your own production?		How much money would you spend if you bought it?	How much did you buy?		How much money did you spend?	How much did you receive from other people?		How much money would you spend if you bought it?
		Unit	Qty		Unit	Qty		Unit	Qty	
Carrots										
Onions										
Garlic										
Okra										
Cabbage										
Cassava leaves										
Kale										
Spinach										
Tomatoes										
Sweet corn										
Squash										
Beans, fresh										
Other										

Fruits	Since last [day of week today] did you or others in your household acquire any [Name of food item]? [1] Yes [2] No	How much did you eat from your own production?		How much money would you spend if you bought it?	How much did you buy?		How much money did you spend?	How much did you receive from other people?		How much money would you spend if you bought it?
		Unit	Qty		Unit	Qty		Unit	Qty	
Bananas, sweet										
Oranges										
Grapefruit										
Lemons										
Avocadoes										
Guavas										
Mangoes										
Papayas										
Other										

Meat (meat in large quantities and not as a condiment)	Since last [day of week today] did you or others in your household acquire any [Name of food item]? [1] Yes [2] No	How much did you eat from your own production?		How much money would you spend if you bought it?	How much did you buy?		How much money did you spend?	How much did you receive from other people?		How much money would you spend if you bought it?
		Unit	Qty		Unit	Qty		Unit	Qty	
Goat										
Sheep										
Beef										
Chicken										
Pork										

Fish / Shellfish	Since last [day of week today] did you or others in your household acquire any [name of food item]? [1] Yes [2] No	How much did you eat from your own production?		How much money would you spend if you bought it?	How much did you buy?		How much money did you spend?	How much did you receive from other people?		How much money would you spend if you bought it?
		Unit	Qty		Unit	Qty		Unit	Qty	
Fish including other seafood (fish in large quantities)										

Eggs	Since last [day of week today] did you or others in your household acquire any [Name of food item]? [1] Yes [2] No	How much did you eat from your own production?		How much money would you spend if you bought it?	How much did you buy?		How much money did you spend?	How much did you receive from other people?		How much money would you spend if you bought it?
		Unit	Qty		Unit	Qty		Unit	Qty	
Eggs										

Milk and other dairy products	Since last [day of week today] did you or others in your household acquire any [Name of food item]? [1] Yes [2] No	How much did you eat from your own production?		How much money would you spend if you bought it?	How much did you buy?		How much money did you spend?	How much did you receive from other people?		How much money would you spend if you bought it?
		Unit	Qty		Unit	Qty		Unit	Qty	
Fresh milk / sour										
Yogurt										
Cheese										
Other dairy products (Exclude butter or small amounts of milk for tea / coffee)										

Oil / fat / butter	Since last [day of week today] did you or others in your household acquire any [Name of food item]? [1] Yes [2] No	How much did you eat from your own production?		How much money would you spend if you bought it?	How much did you buy?		How much money did you spend?	How much did you receive from other people?		How much money would you spend if you bought it?
		Unit	Qty		Unit	Qty		Unit	Qty	
Vegetable oil										
Palm oil										
Shea butter										
Other fats / oil										

Sugar, or sweet	Since last [day of week today] did you or others in your household acquire any [Name of food item]? [1] Yes [2] No	How much did you eat from your own production?		How much money would you spend if you bought it?	How much did you buy?		How much money did you spend?	How much did you receive from other people?		How much money would you spend if you bought it?
		Unit	Qty		Unit	Qty		Unit	Qty	
Sugar										
Honey										
Other sweet (sugary drinks)										

Finished time: …………………….

End of the questionnaire

Thank you!

Appendix Table 9. Check List for the Key Informants Interviews (KIIs)

1. Perception of Climate Change:
   1.1. How have you observed the climate changing in your area over the past 10-20 years?
   1.2. Have they noticed any changes in weather patterns over the past few years?
   1.3. What specific climate-related events have they experienced (e.g., droughts, floods, extreme temperatures)?
2. Impact of Climate Change on Agriculture:
   2.1. In what ways have these changes in climate affected your farming operations and productivity?
   2.2. Can you describe any challenges or impacts you've experienced?
   2.3. Have farmers in your area observed changes in pest and disease pressures due to climate variations?
   2.4. What challenges do they face in adapting to these impacts?
3. Adaptation Measures Taken by Farmers:
   3.1. Have you made any changes or adaptations to your farming practices in response to changes in the climate? If so, what kinds of adjustments have you implemented?
   3.2. Are there any specific practices farmers in your area follow to improve resilience (e.g., crop rotation, soil conservation, water management)?
   3.3. How do farmers in your area access information about climate-smart practices?