SMALLHOLDER FARMERS' KNOWLEDGE OF CLIMATE CHANGE, ADAPTATION STRATEGIES, AND THEIR IMPACTS ON FOOD SECURITY IN DIRE DAWA ADMINISTRATION, EASTERN ETHIOPIA

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This dissertation is dedicated to my dear brother Addisu Rega Amaro and my sister Edlawit Admasu Mezemir. This dissertation would never have reached this level without their unwavering support.

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BIOGRAPHICAL SKETCH

The author was born in 1982 in West Hararghe zone, Mesela town, Oromia National Regional State, Ethiopia. He completed his primary, junior, and secondary school education at Melka Jebdu Primary School, Kezira Primary and Junior School, and Dire Dawa Secondary School, respectively. After passing the Ethiopian School Leaving Certificate Examination, he joined Addis Ababa University in September 2001 and graduated with a BA degree in Sociology and Social Anthropology in 2005.

Soon after graduation, he joined Dire Dawa Local Development Agency as a training and community mobilization officer before pursuing his Master's degree at Haramaya University in 2007/2008. He obtained his MSc degree in Rural Development and Agricultural Extension from Haramaya University in 2009. Following his graduation, he briefly worked as a program coordinator at the Ethiopian Red Cross Society before joining PROPRIDE, a national NGO, as a Regional Project Coordinator for two years. At PROPRIDE, he coordinated Livelihood, Social and Health Programs in Dire Dawa, East Hararghe, and West Hararghe zones of Oromia region.

Mr. Girma currently serves as the Co-founder and Executive Director of Positive Action for Development (PAD), an Ethiopian Civil Society Organization. Under his guidance, PAD has evolved from a city-based NGO to a nationwide entity operating in eight regional states with a workforce of over 420 full-time employees. Over the past decade, he has effectively overseen the management of 120 development and humanitarian programs. Additionally, he holds a certificate in management consultancy from the Ethiopian Management Institute and played a key role in establishing ERA Management Consultancy. Mr. Girma is a co-founder of the Dire Dawa Civil Society Network and holds a board position at the Ethiopian Youth Network for Sustainable Development, a national organization supporting youth-focused initiatives. Furthermore, he currently serves as the Co-Board Chair of Nexus Ethiopia Coalition of Ethiopian Humanitarian Organizations. The author has participated in various international fellowship programs, including the United States Department of Education and Cultural Affairs-sponsored International Visitors Leadership Program (IVLP) in the USA and the Fisher Family Summer Fellows Program at Stanford University Center on Democracy, Development, and Rule of Law in San Francisco/California, USA. Lastly, the author is married and a father of three children.

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ABERRATIONS AND ACRONYMS

ANOVA	Analysis of Variance
CGEM	Computable General Equilibrium Model
CSA	Central Statistical Agency of Ethiopia
EPDRF	Ethiopia Peoples' Democratic Republic Front
FAO	United Nations Food and Agricultural Organization
FGLS	Feasible Generalized Least Squares
GDP	Gross Domestics Product
OLRM	Ordered Logistic Regression Model
GTP	Growth and Transformation Plan
IPCC	International Panel on Climate Change
KMO	Kaiser-Meyer-Olkin
LDCs	Least Developing Countries
MDGs	Millennium Development Goals
MLE	Maximum Likelihood Estimation
MNLR	Multinomial Logistic Regression
MVPRM	Multivariate Probit Regression Model
NGOs	Non-Governmental Organizations
OLS	Ordinary Least Squares
ONRS	Oromia National Regional State
PEM	Partial Equilibrium Model
PCA	Principal Component Analysis
POM	Partial Odds Model
PPOM	Proportional Odds Model
SNNPRS	Southern Nations Nationality and Peoples' Region State
SSA	Sub-Sahara Africa
TAR	Third Assessment Report of International Panel on Climate Change
TLU	Tropical Livestock Unit
UNDP	United Nations Development Program
UNEP	United Nations Environment Program
USD	United States Dollars
VEP	Vulnerability to Expected Poverty

VER	Vulnerability to Expected Uninsured Risk
VEU	Vulnerability to Expected Decline in Utility
VIF	Variance Inflation Factors
WRI	World Resource Institute

TABLE OF CONTENTS

LIST OF TABLES

Table **Page**

LIST OF FIGURES

Figure **Page**

LIST OF TABLES IN THE APPENDIX

Appendix Table **Page**

Smallholder Farmers' Knowledge of Climate Change, Adaptation Strategies and Their Impacts on Food Security in Dire Dawa Administration, Eastern Ethiopia

ABSTRACT

Climate change and variability represent critical global challenges, with profound implications for agricultural productivity, particularly in Ethiopia, where manifestations such as drought and flooding exacerbate vulnerabilities, food insecurity, and rural poverty. Addressing the impacts of climate change necessitates a nuanced understanding of farmers' knowledge, adaptation responses, and the spatial and temporal variations in food security at the micro-level. This study aims to comprehensively assess smallholder farmers' awareness of climate change and its determinants, identify the adaptation strategies they employ, and evaluate the impact of these strategies on household food security. Focusing on rural Dire Dawa Administration in Eastern Ethiopia, we employed a cross-sectional research design, collecting data from 385 farm households through a multi-stage random sampling technique and semi-structured questionnaires. A range of analytical methods, including ordered logit, multivariate probit, endogenous switching regression, and trivariate probit seemingly unrelated regression, were employed. Notably, only 30.5% of respondents demonstrated a high level of climate change knowledge, indicating a significant knowledge gap among the population. Adaptation strategies identified included livelihood diversification (44.88%), soil and water conservation (35.63%), chemical fertilizer use (32.54%), and irrigation (19.95%), with 73.49% of households adopting at least one strategy; however, 59% remained food insecure. The ordered logistic regression revealed that factors such as sex, age, marital status, and access to extension services significantly influenced climate change knowledge. The multivariate probit model also indicated that variables such as education, family size, farm income, and access to credit substantially shaped the selection of adaptation strategies, with evidence suggesting that certain strategies are complementary. Furthermore, the endogenous switching regression model established that the adoption of climate adaptation strategies significantly enhances food security, with adopters experiencing an 11.6% lower daily calorie intake in the absence of adaptation, while non-adopters would see a 12.8% increase in calorie intake if they had adopted climate adaptation strategies. The trivariate probit model underscored the strong interconnections between farmers' climate knowledge, adaptation *strategies, and food security. These findings underscore the necessity for targeted interventions by agricultural stakeholders, particularly policymakers and local development planners, to address the socio-economic, biophysical, and institutional factors influencing farmers' climate knowledge, adaptation choices, and food security status. Such interventions are crucial for enhancing resilience and sustainability in the face of ongoing climate challenges.*

Keywords: Climate change, climate variability, food security, smallholder farmers, adaptation strategies, knowledge, and cross-sectional study

1. INTRODUCTION

1.1. Background of the Study

Climate change represents a long-term, global, or regional shift in average temperature, humidity, and precipitation patterns spanning seasons, years, or even decades (WB, 2022). This phenomenon carries extensive implications across social, economic, political, geographical, ecological, and psychological dimensions (Abbass et al., 2022). In the context of the twenty-first century's global development agenda, climate change has emerged as a pivotal political issue (Buhaug et al., 2022). Notably, agriculture stands as a significant contributor to climate change through greenhouse gas emissions, consequently leading to a reduction in agricultural productivity by approximately 21% (Cornell University, 2021). The repercussions of climate change pose a substantial threat to global economic development, particularly concerning agricultural productivity and food security (Ogundeji, 2022). Acknowledged as an urgent challenge by the United Nations, climate change has continued to escalate, fostering widespread disruption, and loss of life in 2023 (UN, 2023). A recent study published in Nature estimated the global costs of climate change between 2000-2019 at $2.86 trillion, averaging $143 billion per year (Newman and Noy, 2023). These escalating impacts underscore the imperative for reducing greenhouse gas emissions globally and intensifying efforts to adapt and safeguard vulnerable populations. Regrettably, these critical actions are presently inadequately addressed (UN, 2023).

Projections suggest that with ongoing temperature increases and potential precipitation variability, future impacts are likely to exacerbate (Imran et al., 2020; Mihiretu et al., 2020). These forecasts indicate a surge in extreme weather events such as droughts, storms, precipitation fluctuations, and temperature variations in the coming years. Africa is notably susceptible to these adverse consequences (Nangombe et al., 2018). Climate change has already been linked to a 21% decline in agricultural production (Cornell University, 2021), affecting food systems through diminished productivity, livestock losses, and indirect ramifications like food price fluctuations and market instability (Omotoso et al., 2023). Agricultural output is notably sensitive to atmospheric and weather conditions (Dakurah, 2021; Matsalabi et al., 2019), thereby adversely impacting agricultural productivity (Imran et al., 2020), especially in developing nations where climate exerts a predominant influence on agriculture. Additionally, these countries often possess limited adaptive capacities (Badi and Murtagh, 2019; Haile et al., 2020), with Sub-Saharan African economies heavily reliant on climate-sensitive agricultural production, rendering them perpetually vulnerable to these environmental forces (Brügger, 2020; FAO, 2018) exacerbating income disparities within affected regions (Khan et al., 2021). For example, a marginal temperature increases may have negligible effects on wealthier nations' market sectors, they could significantly impair the economies of many Sub-Saharan African countries (Dadzie, 2021).

In Sub-Saharan Africa, challenges related to agricultural productivity, livelihoods, income disparities, ecosystem alterations, agricultural land loss, and susceptibility to food insecurity are particularly pronounced (IMF, 2022). Approximately 40% of the population residing in areas affected by climate change faces multiple challenges and heightened vulnerability to food insecurity due to climatic shifts (Trisos et al., 2022). Numerous researchers have underscored the variability of climate change impacts across countries, emphasizing the role of adaptation and mitigation strategies alongside resource utilization in shaping these impacts (Goglio et al., 2020; Milesi and Churkina, 2020; Lezaun, 2021; Brugger et al., 2021; Ceci et al., 2021).

Within East Africa, climate change-induced issues are escalating with more frequent droughts and floods presenting complex challenges that significantly impact subsistence agricultural productivity and sustainable livelihoods. The region heavily relies on agricultural activities for employment (65.62%), GDP contribution (approximately 37.57%), foreign earnings (80%), and basic necessities for the populace (WB, 2022). Similarly, in Ethiopia, where agriculture contributes significantly to GDP (37.64%), employs around 67% of the population, and accounts for over 79% of foreign exchange earnings (WB, 2023).

Agriculture is recognized as Ethiopia's growth engine and a cornerstone for future economic development and growth (Rubinoff, 2021). However, the disruptive impacts of climate change and variability are destabilizing the nation's economic fabric. The heterogeneous effects across regions and communities underscore disparities in adaptive capacities and effective adaptation strategies' selection to address these challenges. Notably, marginalized subsistence farmers face heightened vulnerability to food insecurity due to limited resilience and weak institutional support for adaptive capacities (O'Connell et al., 2015).

Projections indicate that climate change could annually reduce Ethiopia's GDP growth by potentially reversing economic growth gains by 8-10% by 2050 unless robust policy measures are enacted to mitigate adverse impacts (Simane et al., 2016; CRGE, 2011; McSweeney et al., 2008). Thus, the imperative for immediate and effective actions aimed at building resilience through the adoption of climate-smart and sustainable adaptation strategies is unequivocal (WB, 2022; Simane et al., 2016). Understanding local farmers' comprehension of climate change, their chosen adaptation strategies, and ensuing food security impacts represent crucial steps within the policy framework to address climate change challenges (Nigussie et al., 2017). The dynamic nature of household-level food security/insecurity status underscores variations across locations due to farmers' vulnerabilities or adaptive capacities and potential/residual impacts influencing adaptation strategy choices (Bennett et al., 2016). Selections of adaptation strategies hinge not only on the severity of climate change impacts on food insecurity but also on farmers' awareness of adverse climate effects, adaptive capacities, socio-economic statuses of farm households, and institutional readiness (Grigorieva et al., 2023).

Despite Ethiopia's formulation and implementation of Climate Resilient Green Economy (CRGE) strategies alongside other policies aimed at positioning the nation as a middle-income country resilient to climate change impacts with no net increase in greenhouse gas emissions since 2010 levels, significant strides in reducing food insecurity, pervasive poverty, and vulnerability to climate shocks remain elusive (Tesfaye, 2017). This shortfall may be attributed to insufficient integrated policy implementation frameworks at all levels concerning the systematic understanding of farmers' climate knowledge, effects, and response capabilities. Robust information and knowledge concerning climate change's adverse impacts, adaptation strategy choices, and their food security implications can facilitate the design of sector-specific integrated technical, infrastructural, financial, informational priorities aimed at achieving food security objectives. Such efforts can foster rapid yet sustainable economic growth and development within the country (Tesfaye et al., 2014). Sustainable adaptation policies and strategic support necessitate regular assessments of the evolving landscape of climate change knowledge, its multifaceted impacts, adaptation capacities, and strategies against climate change, as emphasized by Gemeda et al. (2023). The intricate and interconnected effects of climate change on human and environmental systems, alongside the implications for food security stemming from the adoption of climate change adaptation strategies, which exhibit variability across both time and space, remain inadequately explored using rigorous econometric methodologies within the Ethiopian context. Consequently, there exists a notable dearth of knowledge and understanding regarding how the adoption of climate change adaptation strategies (CCASs) influences the food security status of farm households.

This research endeavor aims to delve into the understanding of climate change and its influencing factors among farm households, identify the adoption of adaptation strategies in response to climate change impacts and the factors influencing such decisions, assess the impacts of implementing climate change adaptation strategies on farm households' food security, and explore the intricate relationships among farmers' awareness of climate change, adaptation strategies, and food security within the research locale.

1.2. Statement of the Problem

Climate change presents significant challenges to agricultural productivity and food security globally, with developing nations bearing the brunt of these impacts. In Ethiopia, smallholder farmers—who form the backbone of the agricultural sector—are particularly vulnerable due to their limited resources, knowledge, and adaptive capacity. Given that agriculture is a primary economic driver in Ethiopia, the severe ramifications of climate change necessitate an urgent examination of smallholder farmers' awareness of climate change, their adaptation strategies, and the subsequent impacts on food security within the Dire Dawa Administration of Eastern Ethiopia. These smallholder farmers are disproportionately affected by climate change as they mainly rely on livestock and crop production for their livelihoods. The impact of climate change and variability is adverse in low land or dryland areas like Dire Dawa. In the Dire Dawa Administration, the adverse effects of climate change, notably the rising frequency of droughts and floods, significantly impede agricultural productivity, resulting in food and nutritional insecurities at both household and regional levels (Adugnaw et al., 2014). These extreme weather events are disproportionately affecting smallholder farmers in the area. The administration confronts numerous challenges in adapting to these climate changes. A substantial portion of the population depends on rain-fed agriculture, making them particularly vulnerable to fluctuations in rainfall patterns. Furthermore, limited resources hinder the implementation of comprehensive adaptation strategies, such as improving infrastructure, adopting innovative agricultural practices, and establishing early warning systems.

Empirical studies reveal that smallholder farmers in Ethiopia possess varying levels of awareness regarding climate change and its multifaceted effects. For instance, Moges et al. (2020) found that while many farmers recognize changes in weather patterns, their understanding of the broader implications of climate change remains superficial. This lack of comprehensive knowledge significantly hampers their ability to implement effective adaptation strategies. Furthermore, Teshome et al. (2021) emphasize that educational interventions could substantially enhance farmers' knowledge; however, such programs are scarce in rural areas, leaving many farmers ill-equipped to respond to climate variability. The implications of this knowledge gap are profound, as effective adaptation hinges on a thorough understanding of climate dynamics.

Theories surrounding climate change knowledge systems and adaptive capacity further underscore the importance of local knowledge in shaping adaptation strategies. Pahl-Wostl (2009) argues that higher levels of climate change knowledge enhance adaptive capacity. However, empirical evidence on how climate change knowledge influences farmers' responses to climate change in Ethiopia in general and in Dire Dawa Administration in particular is scant. Many of the research conducted in Ethiopia have either focused on climate adaptation strategies or examined the level of knowledge of smallholder farmers without looking into the interplay between climate knowledge and the use of climate adaptation strategies. This gap indicates a need for research that examines the interplay between smallholder farmers' climate change knowledge and the development of effective adaptation strategies. Understanding this relationship is crucial for designing context-specific programs and interventions.

Research has documented various adaptation strategies employed by Ethiopian smallholder farmers, including crop diversification, soil conservation practices, and the adoption of drought-resistant crop varieties (Hassan & Nhemachena, 2008). However, Beyene et al. (2022) argue that these strategies are often reactive, emerging in response to immediate climatic shocks rather than informed long-term planning. The effectiveness of these strategies is further influenced by socio-economic factors, such as access to credit and extension services, which remain underexplored in the context of Dire Dawa. Understanding these socio-economic dynamics is critical, as they shape farmers' capacity to adapt effectively to climate change.

The relationship between climate change adaptation strategies and food security is inherently complex. Moges et al. (2020) found that while some adaptation strategies may enhance food security, others can inadvertently increase vulnerability due to an over-reliance on a single crop or method. Kebede et al. (2021) emphasizes that food security is influenced not only by agricultural practices but also by market access, infrastructure, and policy frameworks. This multifaceted nature of food security necessitates a more integrated approach to research, where the interdependencies between adaptation strategies and food security are thoroughly examined.

Theoretical frameworks focusing on climate change vulnerability and resilience provide valuable insights into the challenges faced by smallholder farmers. Adger (2006) posits that climate change vulnerability is shaped by exposure to climate risks, sensitivity to these risks, and adaptive capacity. However, the application of these frameworks in the Ethiopian context, particularly in Dire Dawa, remains limited. There is an urgent need to explore how local socio-economic conditions influence vulnerability and resilience among smallholder farmers. Addressing this need will enhance understanding of the unique challenges faced by these farmers and inform the development of tailored strategies to improve their adaptive capacity.
Despite a growing body of literature on climate change and agriculture in Ethiopia, significant research gaps persist regarding smallholder farmers' knowledge, adaptation strategies, and food security impacts. Specifically, there is a lack of comprehensive studies assessing the depth of farmers' understanding of climate change and its implications, exploring the socio-economic factors influencing the adoption of effective adaptation strategies, investigating the complex relationship between adaptation strategies and food security in the local context, and examining the role of local knowledge systems in enhancing adaptive capacity. Addressing these gaps is essential for developing targeted interventions that can strengthen food security and resilience among smallholder farmers in Eastern Ethiopia.

Additionally, a considerable knowledge gap persists, particularly in rural areas, where many individuals lack awareness of climate change and effective adaptation strategies. This deficit severely limits their ability to prepare for and respond to climate-related challenges (Belay et al., 2022). These difficulties are further compounded by ongoing environmental issues, including land degradation, deforestation, and soil erosion, all of which are exacerbated by erratic rainfall, thereby intensifying the impacts of droughts and floods. Scientific research highlights that increasing awareness among farmers about their vulnerability to food insecurity can encourage them to adopt adaptation measures in response to climate variability, contingent upon their adaptability and access to viable options (Gebrie et al., 2023).

While intensive farming practices involving fertilizers, pesticides, and agronomic methods may yield short-term gains, they can have adverse long-term effects on environmental sustainability (Bennett et al., 2016). Balancing economic growth with greenhouse gas emissions is essential to ensure the well-being of present and future generations. Given the dynamic nature of climate change and its multifaceted impacts, including food insecurity and poverty—regular evaluations are imperative to identify emerging challenges. Despite limited studies on farmers' knowledge of climate change, adaptation strategies, and their impact on food security in Ethiopia, there is substantial research focusing on farmers' awareness regarding its effects on local agricultural productivity. For instance, a study by Marie et al. (2020) highlighted institutional and behavioral factors as pivotal determinants of climate change adaptation strategies in Northwestern Ethiopia. Similarly, the World Bank Group (WBG, 2017) examined the awareness levels of families in the Dire Dawa municipality regarding climate change and its impacts. Dessalew (2014) explored factors influencing farmers' comprehension of climate change among various other studies.

While many studies have concentrated on highland regions, there is limited emphasis on lowland areas like Dire Dawa, where the adverse impacts of climate change are pronounced. Consequently, scant literature exists on farmers' knowledge concerning climate change, adaptation strategies, and the repercussions of these strategies on food security. Furthermore, most analyses, such as those by Gebre et al. (2023) and Amare and Simane (2018), have focused on the impact of adaptation strategies on food security using propensity score matching (PSM), which fails to capture the heterogeneity arising from unobservable factors prevalent in food security and adaptation studies (Adgo et al., 2019). Notably, there is a significant gap in research regarding the food security implications of adopting climate change adaptation strategies (CCAS) using the endogenous switching regression (ESR) model, which effectively accounts for heterogeneity due to unobservable factors.

In conclusion, addressing these research gaps is vital for advancing our understanding of smallholder farmers' knowledge of climate change, their adaptation strategies, and the impacts on food security in the Dire Dawa Administration. By conducting comprehensive studies that assess the depth of farmers' understanding, explore socio-economic influences, and investigate the complex interplay between adaptation strategies and food security, this research will significantly contribute to the development of effective interventions aimed at enhancing resilience and food security among smallholder farmers in the region.

1.3. Research Questions

In line with the statements above, this study attempted to answer the following key research questions:

1. What is the level of farmers' knowledge about climate change and what factors determine it in the study area?
2. Which adaptation strategies were pursued by the farm households in the study area to cope with the adverse impacts of climate change?
3. What factors determine farmers' choice of adaptation strategies in the study area?
4. Does the adoption of climate change adaptation strategies improve the food security of farm households in the study area?
5. Do farmers' climate change knowledge, adaptation strategies, and food security have linkages (interdependence) in the study area?

1.4. Objectives of the Study

The general objective of this study is to assess farmers' knowledge of climate change, their choice of adaptation strategies and their impact on farm households' food security in Dire Dawa administration, eastern Ethiopia. Specifically, the study was addressing the following objectives:

1. To measure farm households' knowledge about climate change and identify its determinants in the study area;
2. To identify households' choice of adaptation strategies against climate change impacts and their determinants in the study area;
3. To evaluate the impact of using adaptation strategies on farm households' food security; and
4. To examine the linkages among farmers' knowledge of climate change, adaptation strategies, and food security in the study area.

1.5. Significance of the Study

This study analyzes households' knowledge of climate change, adaptation measures, and the impact of adaptation on food security status, and their linkages. The derived information would support community awareness development regarding climate knowledge; the design of strategies to reduce food insecurity, build institution capacity in the efficient implementation of effective public and ecosystem vulnerability reduction adaptation plans, rain fed agricultural management, and other policy interventions. It can be used as a source of information for local development and the regional climate change and variability action plan (RAP) assessment process for the Dire Dawa administration in Ethiopia. It is believed that the paper is crucial for government officials, NGOs, and researchers at micro (household level) interventions of climate related issues. The derived information would help community awareness creation about climate knowledge; in the design of food insecurity vulnerability reduction and capacity building; to support effective public vulnerability adaption strategy and efficient implementation, sustainable rain feed agricultural management and other policy interventions. The document would be important for government policymakers, NGOs, and researchers as a source of reference for local development planning and national climate change and variability action plan review process about the Dire Dawa City administration in Ethiopia.

1.6. Scope and Limitations of the Study

This study focused on the analysis of farm households' knowledge of climate change, adaptation strategies and the impact of the adaptation strategies on food security. Therefore, smallholder farmers are the target population of the study and were used as the unit of analysis. The study was carried out in the rural Dire Dawa Administration which has been affected by the vagaries of climate change and food insecurity is prevalent. The study is intended to understand farmers understanding of the climate change, how it affects food security, and how they choose to adapt using cross-sectional data. The study's scope was restricted due to time and funding constraints:

The study's first limitation is its geographic scope, which was restricted to the rural Dire Dawa Administration. The second restriction was that farmers' knowledge of climate, its influence on their food security situation, and their choice of adaption strategies not be compared to those of other areas. Because of this, the study was unique and can only be generalized to the Dire Dawa government in Ethiopia. The third drawback of the objective research was that it was only able to address the level of food security, the effects of climate change and variability, and adaptation as a case study in the study region.

The third constraint relates to the use of cross-sectional data; as a result, the conclusions are restricted to static knowledge, food security status, and adaptation strategy choice, which do not consider their dynamism across time. The choice of adaptation techniques, and variables affecting to lessen the impact of climate change, and unpredictability on food security is the study's fourth. Despite all these delimitations, it is believed to have much to offer in terms of policy recommendations and guidance for local development practitioners in the study area (Deressa et al., 2008).

1.7. Organization of the Dissertation

This dissertation was partitioned into six chapters. The first chapter presents the introduction part which includes background, problem statement, scopes and limitations and significance of the study. The second chapter comprises review of relevant literature including the theoretical, analytical, empirical and conceptual frameworks. The third chapter depicted the methodology used in this study. The fourth chapter presents the results and discussions of the key findings of the study. The fifth chapter presents summary, conclusion, and recommendations of the study.

2. LITERATURE REVIEW

This chapter provides the theoretical, methodological, analytical, and conceptual frameworks and empirical literature reviews of the research.

2.1. Definition of Key Terms

Climate: It refers to the average measures of weather conditions recorded over long periods (often 30 years) and the average extremes of weather conditions denote climate shocks (Pratikshya et al., 2014). The onset of climate extremes may be sudden and short-lived (shocks), like flooding, and disease outbreaks, or gradual and continuous stress like drought (Sagara, 2018).

Climate change: It refers to a change in the state of the climate that can be identified by changes in the mean, the variability of the properties, or the regular occurrence of its properties that persists for an extended period, typically decades or longer (IPCC, 2012). It may occur due to natural internal processes or external forcing, or to persistent anthropogenic changes in the composition of the atmosphere or land use. Although it occurs slowly over several years, it can be apparent on a seasonal or multi-seasonal scale as well (IPCC, 2013). It is an important factor for agricultural productivity and hence, its change affects all dimensions of food security namely; food availability, accessibility, utilization, and stability. The country is characterized by rain-fed dependent agriculture.

Thus, together with a low level of socioeconomic development, it is highly affected and vulnerable to the impact of climate change. In this study, climate change refers to the changes in the state of the climate that are apparent both on the multi-seasonal scale and persists at least for a decade or longer.

Farmers' knowledge of climate change: Knowledge has been defined as a highly valued state in which a person is in cognitive contact with reality (Zagzebski, 2017). Climate change knowledge therefore is a person's cognitive contact with the reality or facts about climate change (Weber and Stern, 2011). The behavior needed to mitigate the negative impacts of climate change may be strongly influenced by how individuals and communities perceive the risks and impacts of climate change (Chowdhury et al., 2021). Therefore, the accuracy of people's climate change knowledge is of paramount importance for societies to undergo the transformations needed to mitigate and/or adapt to climate change (Busch et al., 2019; Trott, 2020). However, studies show that many people have limited knowledge, misconceptions, and misunderstanding about the causes and impacts of climate change (Acquah, 2011; Dawson, 2015; Boon, 2016; Varela et al., 2020).

Food security: It is defined by various agencies and organizations differently without a significant change in its basic concept. For instance, Smith et al. (1993) and Gentilini (2002) identified about two hundred and five definitions of food security. However, the most commonly accepted definition that was approved by the 1996 World Food Summit is the definition given by the Food and Agricultural Organization (FAO). They defined food security as when all people at all times have physical and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life (FAO, 2017).

FAO's (2017) definition has established four pillars of food security namely; food availability, accessibility, utilization, and stability. Food availability refers to the amount of food that is present in a country or area through all forms of domestic production, imports, stocks, and aid, and hence, achieved when adequate food is available at the disposal of individuals. Food is accessible when households and individuals have sufficient resources to secure appropriate foods in terms of quantity and quality for a nutritious diet. Food utilization refers to the ability of the human body to ingest and metabolize food. Hence, the food should be nutritious and safe for consumption in an adequate biological and social environment with proper health care. Food security is not a onetime event; rather it occurs permanently with sustainability. Hence, stability describes the temporal dimension of food security, the time frame over which food security is being considered and achieved when the supply on the household level remains constant during the year and in the long-term.

Adaptation: It refers to adjustments in ecological, social or economic systems in response to actual or expected climatic stimuli and their effects (IPPC, 2007a). It refers to changes in processes, practices and structures to moderate potential damages or to benefit from opportunities associated with climate change.

Adaptation strategy: An adaptation strategy is a program, project or approach that has been developed to respond to anticipated climate change impacts in a specific area of potential concern.

Adoption: It is defined as the decision to use new technology, methods, and practices by economic units regularly (Rogers, 1983; Feder et al., 1985; Langyintuo, 2008). It can occur either at the individual farm or aggregate level. Adoption at the household level reflects a farmer's decision to incorporate a new practice/technology into the production process whereas aggregate adoption reflects the process of spreading or diffusion of a new technology/strategy within a region or population. Hence, a distinction exists between adoption at the individual farm level and aggregate level**,** within a targeted region or geographical area (Feder et al., 1985). According to him, technology is adopted only when it is implemented continuously in the farmers' field and fully integrated into the household farming system.

The process of adoption decision includes the simultaneous choice of whether to adopt a strategy or not and its intensity of use. Hence, it involves the choice of how much resource to allocate to the adaptation strategy if the strategy is not divisible. On the other hand, if the strategy is divisible, the decision process involves area allocations as well as the level of use or rate of application (Feder et al., 1985). However, the decision of whether or not to adopt a given technology/strategy is not an overnight phenomenon. It is a mental process that passes through different stages. Hence, the adoption process of practicing a certain adaptation strategy at the farm level starts with the awareness creation of the adopter about the existence of the specific adaptation strategy. Then, the potential adopter analyses the information about this strategy and gets to further understand the attributes of the adaptation strategy. After that, the potential adopter would have made a trial or experimentation before adopting the strategy. Based on the perceived benefits of the strategy, the individual goes to the actual stage of adoption of the strategy/ies. Once the strategy is adopted, the adopter may decide to continue using it or discontinue, based on the experience and benefits obtained after the adoption of those strategies (Simtowe et al., 2016). Hence, in this study, adopters refer to those smallholder farmers who decide to adopt climate change adaptation strategy/ies such as soil and water conservation, livelihood diversification and chemical fertilizers on their farm during the survey year.

Impact: It is the positive and /or negative, intended and /or unintended, direct and/or indirect, primary and/or secondary effects produced by an intervention and hence, it investigates the changes brought about by the intervention and the expected results (Khandker et al., 2010; Gertler et al., 2011). Impact evaluation includes evaluation containing an estimate of what would have happened on food security status of farm household if he/she had not adopted climate change adaptation strategies. It includes a comparison of groups who adopt adaptation strategies with a group who did not adopt them. The major reason for doing an impact evaluation is to decide whether or not to continue or expand an intervention, to learn how to scale up and successfully adapt a successful intervention to suit another context and to inform intended beneficiaries about the advantages of an intervention.

2.2. Theoretical Framework

2.2.1. Farmers' Knowledge of Climate Change

The study by Hurni et al. (2015) argues the knowledge advantage related to climate change impacts in the assessment of climate change and variability status by agricultural farmers and their stakeholders such as experts, policymakers, and others on periodic climate change and variability status. According to them, the status of climate change and variability changes over time and space, and regular assessments are needed to take action against the adverse impacts of climate change.

Farmers' knowledge of climate change expressed in rainfall, topography, and the status of which land before and field level factors (soil type, slope, and location of the plot) affect agricultural practices (Kondolf and Podolak, 2014; Vu et al., 2014). It also affects the institutional factors including contacts with the agricultural extension agents (affecting access to information on climate change and variability and its impacts), response adaptation strategies (for demonstration effects), and the impacts on different sectors are crucial to designing complementary and integrated policy related to climate change adaptation planning. Household characteristics including education, age, gender, family size, the source of livelihood, and others are also important (Dessalew, 2014).

The impact and pattern of climate change and variability vary by location and time (Waswa et al., 2013; Dahal et al., 2014). Currently, climate change and variability are causing immediate and underlying impacts that are increasingly attracting policy attention as they are highly related to farmers' knowledge, derived from understanding physical climate change and variability and its impacts on humans and crops environment originates and behavioral decisions are developed. It also has implications for policy-making and implementation success that result from systematically understanding the cause or/and resolution of climate change intensities and impacts and variability (Schreiber et al., 2012; Agyemang, 2012; Bisaro et al., 2014; Kiage, 2013).

There are various factors that influence farmers' knowledge of climate change and variability, including physical factors or village level, socioeconomic, environmental and institutional factors (China et al., 2007; Abdulrashid and Mashi, 2014). Assessing smallholder farmers' knowledge of climate change and variability in a given location using indicators of climate change and variability such as precipitation, wind, temperature, drought, flood and insect infestation may not be sufficient (Muia, 2013; Abdulrashid and Mashi, 2014). Therefore, household and institutional characteristics such as age, education, contact with extension, etc. also influence farmers' knowledge about climate change, adaptation strategies and food security (Chizana et al., 2007).

In the case of climate change, reductions in animal production and reproduction, reductions in herb cover, changes in plant species composition, declines in plant abundance, declines in important forage species, and the disappearance of beneficial plant species are some of the common types of knowledge indicators (Akinnagbe and Umukoro, 2011; Abdulrashid and Mashi, 2014; Dembele, 2006; Ward et al., 2000). This change varies according to the spatial and temporal perspective, also for different livestock species and the presence of certain weed species (Abdulrashid and Mashi, 2014). Malley et al. (2006) and Reed et al. (2007) confirmed the occurrence of invasions of weeds and inedible species. Previously unknown grasses and weeds that have no economic benefit can be considered as inducers of climate change and rangeland and range variability (Abdulrashid and Mashi, 2014).

2.2.2. Food Insecurity

Vulnerability to food insecurity is a single fuzzy word with many definitions based on the context under consideration. The two best-known definitions were provided by the European Social Policy Network (ESPN) and the International Panel for Climate Change (IPCC). According to ESPN (2005), vulnerability is the degree of fragility of a person, group, community or state to defined hazards or threats. IPCC (2007) also defines vulnerability as the extent to which a system is vulnerable to adverse impacts of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and the variation to which a system is exposed, its sensitivity, and its ability to adapt.

People in most developing countries especially whose economy is highly depending on low productive agriculture due to the impact of climate change and variability and other socioeconomic and institutional factors are vulnerable to their impact (Kaly et al., 2004). As most developing countries are depending on their environmental assets; their livelihood will be vulnerable to the impacts of this climate change and variability. Climate change and variability could be one component of a complex (syndrome) of impoverishment but is rarely construed as a singular component that equates with vulnerability (UNEP, 1987).

In this study, food insecurity is described as the vulnerability of agricultural households to the impacts of climate change and the variability in the socioeconomic status of households living in degraded areas. Most often, the impacts of climate change and variability are not isolated single stresses and shocks in nature, but there are many interconnected complex relationships between causal functional relationships with, for example, climate change; it is the status of the individual or group before impact. When examining food insecurity, the extent and cause are important questions in order to target interventions to mitigate or minimize it. Various theoretical models have been developed by academics to determine who food insecure is and to what extent in relation to pre-existing coping and adaptability based on a sustainable livelihood framework (Kaly et al., 2004).

There are different theoretical frameworks developed by scholars to assess food insecurity. The following frameworks are the common but not limited to these only. The most common food insecurity assessment frameworks including availability, access and, affordability approaches in terms of quantity, quality or calories described in the following subsections sections.

2.2.2.1. The neoclassical framework

The neoclassical framework for analyzing food insecurity among farm households primarily focus on the macro-level economic factors that influence food availability and access. This include: First, supply and demand which examine how the supply of food (through agricultural production) and the demand for food (based on population needs) interact and any imbalance can lead to food insecurity. The second is the market mechanisms where prices play a crucial role. If food prices are too high, it can limit access for poorer households. Conversely, low prices might discourage farmers from producing enough food. The policy interventions where government policies, such as subsidies, tariffs, and trade regulations, can significantly impact food security. Effective policies can help stabilize food prices and ensure a steady supply. The third is resource allocation which looks at how resources like land, water, and labor are allocated and utilized in agriculture. Efficient use of these resources can enhance food production and security. Finally, economic shocks where factors such as inflation, unemployment, and economic downturns can affect household incomes and their ability to purchase food, leading to food insecurity (Sassi, 2018; Mota et al., 2019).

2.2.2.2. The sustainable livelihood approach (SLA)

It is a holistic framework used to understand and address food insecurity among farm households. It focuses on enhancing the capabilities, assets, and activities required for a means of living, particularly in rural areas. Here are some key aspects of how SLA addresses food insecurity: Asset-based framework which emphasizes the importance of various assets (human, social, natural, physical, and financial) that households need to secure their livelihoods. By strengthening these assets, farm households can better cope with and recover from food insecurity. The second approach is the vulnerability context which considers the external factors that affect livelihoods, such as climate change, economic shocks, and policy changes. Understanding these factors helps in designing interventions that reduce vulnerability and enhance resilience (Amoah and Simatele, 2021). The third approach is the livelihood strategies which encourages the diversification of livelihood strategies to reduce dependency on a single source of income. This can include combining farming with other activities like small-scale trading or handicrafts (Abdallah et al., 2021). The fourth approach is institutional and policy context which looks at the role of institutions and policies in shaping livelihood outcomes. Effective policies and supportive institutions can provide the necessary resources and infrastructure to improve food security (Su et al., 2021). The last approach is sustainability which ensures that interventions not only address immediate food insecurity but also contribute to long-term resilience and environmental sustainability (Ado et al., 2019). By integrating these elements, the SLA provides a comprehensive framework for tackling food insecurity among farm households, promoting both immediate relief and long-term resilience.

2.2.2.3. The household economy approach (HEA)

It is a method used to assess the vulnerabilities of households, particularly in rural areas, to economic shocks and changes. This approach is based on understanding livelihood patterns and market information. It helps in monitoring food security and adaptation to climate change, and informs relevant policy responses and initiatives1. In the context of farm households, food insecurity can be influenced by several factors, including access to credit, adoption of improved crop varieties, and socio-economic characteristics such as education and gender (Acheampong et al., 2022; Ogunniyi et al., 2021). For instance, studies have shown that improving access to credit and encouraging the adoption of improved agricultural practices can significantly enhance food security among farm households (Acheampong et al., 2022; Ogunniyi et al., 2021).

2.2.2.4. The theory of access

It is developed by Ribot and Peluso (2003), and provides a comprehensive framework for understanding food insecurity by examining how different factors influence access to resources. This theory goes beyond the traditional focus on property rights and considers a broader range of social, economic, and political factors that affect people's ability to obtain resources necessary for food security (Mutea et al., 2020). Key elements of this theory include: Bundle of rights which refers to the legal rights individuals or groups have over resources, such as land ownership and bundle of powers which encompasses the broader social, economic, and political factors that influence access to resources, such as social networks, technology, and authority (Mutea et al., 2020). For example, in a study around North-West Mount Kenya, it was found that food insecurity was not solely due to a lack of property rights. Instead, difficulties in accessing farm technology and social relations played a significant role (Mutea et al., 2020).

2.2.2.5. The resilience index measurement and analysis (RIMA)

It is a methodology developed by the Food and Agriculture Organization (FAO) to measure and analyze household resilience to food insecurity. It uses a quantitative approach to establish a cause-effect relationship between resilience and its critical determinants (FAO, 2018). RIMA is context-specific and can be adapted for impact evaluation, reflecting the Theory of Change (ToC) and Logframe of interventions. It is used within a Monitoring, Evaluation, and Learning (MEAL) framework to track progress, explore changes in food security and resilience over time, and improve program design and policy decisions (FAO, 2018). The methodology has been applied in various countries across Africa, the Middle East, Asia, and South America, helping to build national and regional capacities for resilience analysis (FAO, 2018).

In this study, the SLA framework for food insecurity was used as it is a comprehensive framework for tackling food insecurity among farm households, promoting both immediate relief and long-term resilience.

2.2.3. Adoption of Climate Change Adaptation Strategies

Many frameworks have been established to study adaptation. A sustainable lifestyle, rational choice or rational action, and utility theoretical frameworks are the most popular adaptation theoretical frameworks. The theoretical framework used relies on the goals of the study and the accessibility of the data.

2.2.3.1. Sustainable livelihood framework

The ability and asset (natural capital, social capital, human capital, physical capital, and financial) in the livelihood to adapt external (stress, shocks, trends, and other environmental changes) that affect the welfare of economic agent, in this case farm households, are identified using the livelihood approach framework (CARE, 2011). As sources of livelihood and environmental changes (risks) are dynamic; vulnerability to climate change (status), scales and factors influencing both private (autonomous) and planned (public) strategies should focus to the correct policy target to a spatial variable and timely dynamic problem (IPCC, 2007). This model, assumes human as a center of development, using livelihood assets as a means of an institution as an instrument to adjust the resource to moderate the prevailing vulnerability status (Ian, 2015).

2.2.3.2. Rational choice framework

Rational action theory, commonly referred to as rational choice theory, is the second most popular theory in vulnerability adaptation choice. This hypothesis is based on an observer's expectations for how a choice should turn out. This indicates that, according to Simon's (1957) formulation of the calculated choice theory and process, which he dubbed "perfect and otherwise, bounded reality". Humans attach a problem solver to a limited supply of resources when reality is confined the capacity for processing information. The most typical example used in the selection of adaption methods based on benefit-cost analysis utilizing data is that if option "A" is more viable than option "B," then "A" is always chosen over "B," and if "B" is more feasible than alternative "C," then "B" is preferred.

2.2.3.3. Random utility framework

The susceptibility of civilizations to climate change and unpredictability, or to any environmental change, is a discrete choice issue. This utility model posits that each adapter will want to maximize his or her utility while selecting a strategy. Assume there are j choices that make up S_j strategies (S_1, S_2,... S_j). All decision-makers or adapters are aware of the benefits of each approach and are able to rank their utility preferences for each alternative method. However, the researcher only understands the systematic characteristics of a person, not the utility of that individual (Kato et al., 2011).

Since specification errors are a capture property of the representative utility, which influences the decision maker but not the researcher, the set is considered to be randomly distributed. When a single farmer adapts S_n alternatives, he or she has an option among many Sn alternatives, an index with arbitrary order. Assume that U_{is1}=S_1, S_2..., S_n represents the utility that person i assigns to each alternative. If it can be predicted that option j would provide him with the most utility, the farmer will favor it.

This methodology presupposes that the utility function's error terms are independently and identically distributed (IID), with their distributions being normal (Manuel and Dietmar, 2017).

The preferred adaption techniques and their drivers are identified in this study using the random utility framework.

2.2.4. Impact Evaluation

Newman et al. (1994) started the impact evaluations of development initiatives when they presented the need for thorough impact evaluation in international development in a World Bank Research Observer study. At the time, the World Bank was supporting early RCTs in Latin America. After almost a decade, the World Bank's Development Impact Evaluation effort and J-PAL (the Abdul Latif Jameel Poverty Action Lab) were established in 2003 and 2004, respectively. The international initiative for impact evaluation was established as a result of the widely read study when will we ever learn? (Savedoff et al., 2005) by the Centre for Global Development, which made the case for a global fund for impact evaluation. The last fifteen years have seen an almost exponential increase in impact evaluations studies, particularly in randomised controlled trials (Cameron et al., 2016; White and Masset, 2018). However, as the corpus of research has expanded, a new difficulty has emerged: how to keep up with the increasing amount of information and how to objectively and consistently inform policy (Lawry et al., 2017).

Furthermore, there were various theories of technology adoptions as discussed above. Among them a utility maximization theory contends with the fact that customers should try to get the most out of the goods and services they use to maximize their utility or satisfaction, assuming that customers have rational preferences and make decisions based on their financial limitations (VonNeuman and Morgenston, 1944; Smith, 2001). Similarly, when several agricultural technologies are adopted, the selection of those technologies is based on the anticipated advantages of adopting particular options in light of the adopters' constraints. If the benefits of adopting agricultural technologies outweigh the costs, or if the expected utility from adoption is greater than the expected utility from non-adoption, a farm household may choose to adopt one or more agricultural technologies (Menale et al., 2013). Hence, for this study, to examine the impact of adoption of adaptation on food security, utility maximization theory was adopted.

2.3. Methodological and Analytical Frameworks

The methodological and analytical frameworks of the study are described in this section. The entire research process is guided by a methodological research philosophy that starts with ontology (the nature of the world under study) and ends with epistemology (the approaches and procedures to search the reality). The next subsections address the methodological and analytical frameworks of the study which serve as the fundamental rules for the research procedures utilized to achieve the various study objectives.

2.3.1. Methodological Framework

The research methodology applied depends on the research philosophy, which influences the curriculum and the instrument chosen. Assumptions about the type of truth being studied influence research methodology. The positivist philosophy of research assumes that the truth under investigation is quantitative in character and has been objectively established. It follows that reality is stable and can be viewed and described objectively without detracting from the subject of study (Levin, 1988). The quantitative paradigm states that from an ontological point of view there is only one truth. There is an objective world separate from human perspective. Epistemologically, the investigator and the object of investigation are separate parties. The goal is to quantify and study the interactions between variables within a valueless framework (Denzin and Lincoln, 2000). It is believed that quantitative approaches are the only way to examine results and present them to an audience. In contrast to these positions, which have been taken throughout the research process, and despite the fact that the researchers themselves are members of numerous social groups, positivism has come under heavy attack for its use in attempting to analyze social phenomena. This ignored the reality that many decisions are made by people and are therefore subjective.

In response, a new concept emerged known as the constructionist, interpretations, and naturalist, which calls for a reexamination of positivism's ontological, epistemological, and axiological beliefs. The interpretivist paradigm underpins the qualitative paradigm (Seeker et al., 1995; Altheide and Johnson, 1994). According to ontology, there are multiple realities or truths depending on how one defines reality. Realities are socially produced and dynamic (Berger and Luckmann, 1966).

There is no way to reach a reality that is not a product of human thought, and there is no external standard by which to judge the veracity of truth claims (Smith, 1983). Interaction between the researcher and the subject of the study allows for the creation of results in the context of the scenario (Denzin and Lincoln, 1994; Guba and Lincoln, 1994). According to this, reality doesn't exist before an inquiry is conducted, and it vanishes when the investigation is over (Smith, 1983). Qualitative research places a strong emphasis on processes and meanings.

The purpose of this study is to evaluate the knowledge of farm families on climate change and variability, adaptation strategy choosing behavior, and its impact on food security. These research approaches were constructionist and interpretivist in nature because they assumed that knowledge about climate change is socially built and interpretive. According to positivist research methodology, the degree of food insecurity among farm households as a result of climate change will be calculated using quantitative and qualitative data. Furthermore, utility theory, which is arbitrary and belongs to the philosophy of constraints or interpretation, will be the foundation for farmers' adaptation judgments and their selection of adaptation tactics. In order to achieve its goals, this research will combine the positive, constructionist, and interpretive research philosophies.

This study will employ survey-based data gathering methodologies and policies based on the pragmatism scientific paradigm's guiding principles (Cooper and Schindler, 2006). The deductive method will be used because the research was conducted using established interrelated multiple theories of regarding climate change, farmers vulnerability, and the selection of adaptation strategies; and (Creswell, 2009). Statistical models utilized in exploratory research to understand the connections or links between dependent and independent variables. Data from many countries was gathered for the study utilizing a semi-structured questionnaire.

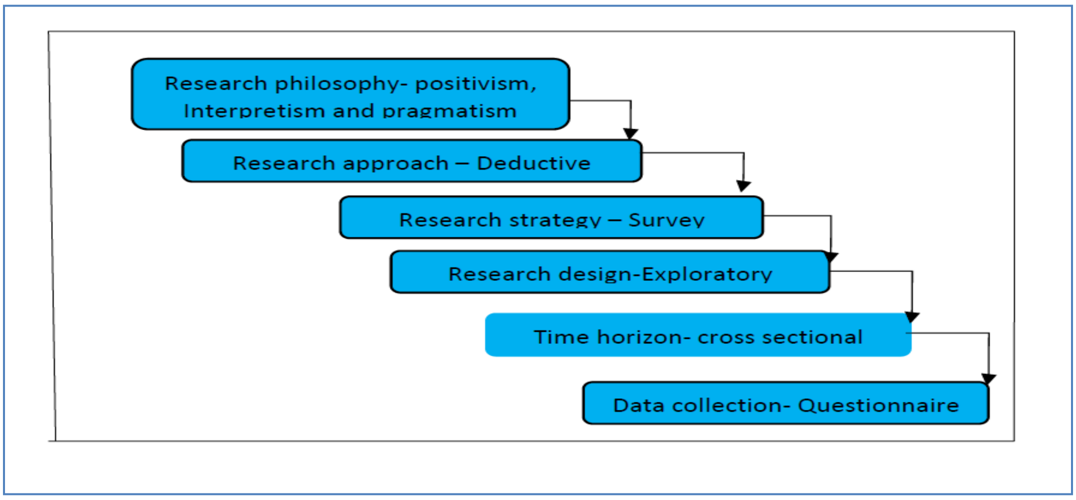

Figure 1: The methodology of the research

Source: Adopted from Saunders et al. (2007)

This study used survey research, a modern research methodology that is founded on the scientific paradigm of pragmatism (Cooper and Schindler, 2006). It is a confirmatory research kind in nature and also a deductive technique as the investigation will adhere to the accepted hypotheses (Creswell, 2003). Mixed paradigm study which incorporated both qualitative and quantitative data types was used in this study.

2.3.2. Analytical Framework

This sub-section presents the data analysis methods used to address the determinants of farm households' knowledge, choice of adaptation strategies, and their impacts on food insecurity and the linkages among knowledge, adaptation, and food security in the rural Dire Dawa City Administration.

2.3.2.1. Measurement and determinants of climate change knowledge

In the study by Madaki et al. (2023), farmers were asked seven quiz questions on farming practices related to climate change mitigation to indicate their level of climate change knowledge. The seven quiz questions were based on deforestation, land clearance by bush burning, fossil fuel use, methane ($CH4$) from livestock production, use of chemical fertilizers and other agrochemicals. Each question answered correctly by a farmer received a score of 1, and a wrong answer or "I do not know" received 0. The scores for each farmer were summed up, with the final count score ranging from 0 to 7. They used the Poisson regression model to identify factors affecting the climate change knowledge of farmers.

Zobeidi et al. (2020) categorized knowledge into knowledge of causes with indicators (climate change is caused mostly by human activities and climate change is caused more or less equally by natural changes in the environment and human activities) and knowledge of consequences with four indicators (Climate change will increase the negative public health impacts, climate change will decrease the sea level, climate change will increase the droughts and climate change will increase the insects) both measured in five points Likert scale (1= Strongly disagree, 5= Strongly agree). They used Cronbach's Alpha coefficient as a measure to represent the reliability and refined the statements to finalize the questionnaire. They used the Structural Equation Modeling (SEM) procedure to identify the determinants of climate change knowledge of farmers.

The study by Yazdanpanah and Azadi (2019) also measured farmers' knowledge about climate change and identified factors affecting their knowledge about climate change using structural equation modeling (SEM). They measured farmers' knowledge using knowledge indicators measured on a 1–5-point scale (very low, low, moderate, high, and very high).

Ofori et al. (2023) measured climate change knowledge as follows. They awarded a score of 1 to a correct ('True') answer, while a score of zero was awarded to incorrect ('False' or 'Not Sure') answer for the knowledge questions, giving a total score of 5 (100%). The respondents were said to have "very good-excellent" knowledge of climate change if they had a score of 90% and above, "adequate" knowledge of climate change if they scored from 75 to 89%, "average" knowledge of climate change if they scored 50 to 74% and "inadequate" or "poor" knowledge on climate change if they scored below 50%. They used the logit model to identify factors affecting students' knowledge of climate change.

A study by Tesfaye (2017) used a qualitative binary response model (logit model) to examine how knowledge about climate change and variability relates to other socioeconomic and biophysical aspects in agricultural households in Ethiopia. To measure climate change severity and variability based on variation in farmers' knowledge components using qualitative or quantitative agricultural yield reductions and other related views, Zerihun et al. (2016) assessed household climate change and variability intensity of perception using a Likert-scale from very low to very high and used ordered logit model to identify its determinants. This method provides more information than a binary model. Oremo et al. (2019) measured farmers' knowledge of Integrated Water Resources Management (IWRM) as an adaptation strategy against climate change stresses by asking them to rate their understanding of the concept on a four-point Likert scale of good, average, poor, and no understanding and identified the determinants of farmers' knowledge of IWRM using Ordinal logistic regression model. In this study, we followed Ofori et al. (2023) measurement of climate change knowledge of farmers.

2.3.2.2. Determinants of choice of adaption strategies

Farm households use different strategies when they understand the adverse impact of climate change on their agricultural productivity and welfare. However, climate change impacts and the understanding and farmers responses varies from location to location based on their social, economic, institutional and biophysical factors.

The type (nature), relative complementarity or substitution of the choices and type of study determine the selection of the model to be used in identifying the determinants of adaptation (Haensel et al., 2011). Econometric models such as multinomial probit (MNP), multinomial logit (MNL), and multivariate probit (MVP) are effective for the analysis of categorical dependent variable choice for unordered sets.

The MNP model, according to Dow and Endersby (2004), belongs to a class of multinomial choice and more flexible logit-type specifications that includes the generalized extreme value. As a function of chooser and choice attributes, they describe choice as a decision among unordered alternatives. MNP does not require the assumption of independence, and developments in computer technology make its estimation more feasible. As a result, one may argue that MNP should be the gold standard methodology for studying multiple choices of unordered nature (Komba and Muchapondwa, 2018).

The MNL model is used in unordered data analysis of decisions with more than two categories, which allows determining choice probabilities from different categories (Deressa et al., 2009; Belay et al., 2017). The probability of the MNL model is optimized to its global maximum, except under circumstances of profound misspecification, and is not prone to optimization errors. In addition, the model is manageable and easy to estimate, making the formulation of the MNL model simple and desirable. MNL is the most commonly used model because it is easy to calculate. However, this model makes a very restrictive assumption that the choice of adaptation methods is independent across alternatives, referred to as the irrelevant-alternative-independence (IIA) assumption (Wooldridge, 2002). This assumption is difficult because farmers' adaptation strategies are influenced by a variety of circumstances.

When individuals can only choose one practice from a set of mutually exclusive alternatives, multinomial logit and multinomial probit models are viable models (Leeflang et al., 2015). This is strongly related to the notion that all disturbances are mutually independent, and they do not take into account the probable inter-relationships between various rehabilitation procedures (Yu et al., 2008). When attempting univariate modelling, useful economic information contained in interdependent and simultaneous adaptation decisions is excluded. As a result, when adaptation methods are interconnected, such models are improper to use (Belderbos et al., 2004).

Failure to account for unobserved elements and the interdependence of adaptation decisions may result in inefficient and erroneous estimation (Greene, 2008). Farmers are more likely to embrace a package of climate change adaptation strategies that maximize their projected utility in dealing with a variety of climate change risks and restrictions than they are to adopt a single sustainable climate change adaptation activity. In this case, MVP which captures adoption of multiple technologies and their possible interdependence is preferred.

Hence, in this study MVP model was used to identify the determinants of farmers' adaptation strategies which address the possibility of adopting multiple strategies and the probable interrelationships between them.

2.3.2.3. Impact of adoption of climate change adaptation strategies on food security

There are various alternative models that are used for evaluation of the impact of adoption of a technology/strategy as a dummy variable with cross-sectional data. Accordingly, randomized control methods (RCM), propensity score matching (PSM), regression discontinuity design, instrumental variables (IV), and endogenous switching regression are the most common ones.

Randomized Selection Methods (RSM): These are the processes of randomly selecting both treatment and control groups from a clearly defined population to evaluate the outcome of an intervention. Hence, the control group is similar to the treatment group and only differs in terms of participation in the needed program (Abadie et al., 2004). It is also used to assess the impact of a program when the participant is randomly selected.

Propensity Score Matching (PSM): It is mostly used for estimating a causal effect of a binary treatment framework. It is a statistical matching technique that, when observable variables are employed in the absence of baseline data, can aid in reducing bias in observational research. Although it can be applied to the analysis of more than two groups, its main use is in the comparison of two subject groups (Rubin, 2001). By computing the estimated covariance of therapy, it determines the impact of the treatment program or policy. According to Khandker et al. (2009), the PSM approach aims to capture the impact of covariate X in treatment groups that are seen differently on the propensity score or single index. To assess a program's impact, results are compared between program participants and non-participants who have the same propensity score. According to Rosenbaum and Rubin (1983), the propensity score is a conditional probability for treatment groups based on pre-intervention variables. Additionally, it is a frequently employed technique by scholars due to its consideration of the counterfactual and ability to overcome issues with contamination and selection bias.

Regression discontinuity design (RDD): It is one of the rigorous quasi-experimental impact evaluation approaches that can be used to estimate program impacts in situations in which candidates are selected for treatment based on whether their value for a numeric rating exceeds a designated threshold or cut-point (Jacob et al., 2012). It allows us to account for observed and unobserved heterogeneity. It initially assigns scores for the intervention unit and then compares the outcome of individuals above the cut-off point with a group of individuals below it. Individuals around the cut-off point are assumed to be similar.

Instrumental variables (IVs): These are used to control for confounding and measurement errors in observational studies. However, if instruments are weak, confounders produce large standard errors which results in imprecise and biased results. Hence, it is not an appropriate model if there are strong confounding effects. Similarly, it takes care of unobservable characteristics and deals with the problem of endogenous treatment. Hence, it is suitable to deal with potential endogeneity problems mostly for linear problems. It also assumes the existence of at least one variable Z called an instrument that explains treatment status (Abadie et al., 2004).

Endogenous Switching Regression (ESR): It is also used for impact study. It is used to reduce selection bias and ensure reliable outcomes (Singh et al., 1986). It is also used to correct potential endogeneity problems for nonlinear models by estimating two separate selection equations (Moti et al., 2018). Hence, it is used to take care of both observable and unobservable characteristics.

Hence, for this study, an endogenous switching regression model was employed to effectively evaluate the impact of the adoption of CCASs on the food security of farm households in the study area.

2.4. Empirical Literature Review

This section includes empirical research on climatic variability and change. The next subsections evaluate related literature on knowledge, food insecurity, and their adaptation strategies.

2.4.1. Farmer's Knowledge about Climate Change

Studies on climate fluctuation and change research have been done in some nations, including Ethiopia. Dessalew (2014) used primary data from farm households in Ethiopia to examine farmers' knowledge about climate change and its determinants in Ankesha district of Amhara National Regional State. The results of the logistic regression model analysis showed that the household head's educational level, land insecurity, extension contact, and slope, the distance of the plot from the residence, and plot size were the most important factors.

To assess farmers' knowledge of the impact of climate change and variability on agricultural productivity in Oromia National Regional State West Shoa zone Jeldu district, Tesfaye (2017) used a binomial logistic regression model. The result shows that farmers in the study area perceived and observed the following signs of soil erosion and loss of soil fertility: gully formation, soil accumulation around clumps of vegetation, soil deposition on gentle slopes, exposed roots, muddy water, deposition in streams and rivers, change in vegetation types, increased runoff and reduced rooting depth. Moreover, results show that institutional, psychological, demographic, and biophysical variables were the main determinants of farmers' knowledge of the impacts of climate change and the hazards of variability on agricultural productivity.

The study by Yazdanpanah and Azadi (2019) also measured farmers' knowledge about climate change and identified factors affecting their knowledge about climate change using structural equation modelling (SEM). They measured farmers' knowledge using knowledge indicators measured on a 1–5- point scale (very low, low, moderate, high, and very high). The results of SEM revealed that the (standardized) path coefficients indicate the strengths of relationships between the variables (Knowledge of climate change, environmental attitude, trust, self-efficacy, and risk attitude). In the model, knowledge of climate change was selected as the dependent variable and environmental attitude, trust, self-efficacy, and risk attitude as independent variables and entered into the SEM. Path relationships revealed that the environmental attitude, trust, and risk attitude are significant predictors of the knowledge of climate change. These variables predicted about 25% of the variance in knowledge of climate change. Environmental attitude appears to contribute most to the model followed by risk attitude and trust. Paths from self-efficacy to knowledge of climate change were not significant.

Oremo et al. (2019) measured farmers' knowledge of Integrated Water Resources Management (IWRM) as an adaptation strategy against climate change stresses by asking them to rate their understanding of the concept on a four-point Likert scale of good, average, poor and no understanding and identified the determinants of farmers' knowledge of IWRM using Ordered logistic regression model. Their results show that education measured in year in schooling, the type of livelihood, access to extension from the government member of environmental network as the significant factors affecting farm households' knowledge of IWRM. These results are compatible with chi-square test that shows that knowledge of IWRM among irrigators was significantly related to level of education, access to extension and level of income. Farmer educational workshops and chief's forum (54.6%) were the main sources of water resources management information.

2.4.2. Determinants of Choice of Climate Change Adaptation Strategies

Numerous studies have been conducted in Ethiopia and other countries on adaptation to various environmental changes affecting vulnerability and adaptation mechanisms. Using multinomial logistic regression (MNLR) to identify local farmers' adaptation strategies and their determinants, Betelhem (2014) assessed smallholder farmers' knowledge of adaptation strategies to mitigate climate change impacts/variability among farmers of two kebeles in Dire Dawa Municipality in Ethiopia. The primary determinants for adjusting farmers from the analysis results are their gender, education, the amount of available active household labor, off/non-farm income, frequency of advisory contacts, access to credit, their proximity to markets, their knowledge of the local climate, the size of their farms, their level of farming experience, and their ability to gain access to irrigation. Research's ability to rank the relevance of the tactics is subject to certain limitations.

In Adola Rede Woreda, Oromia region, Aschalew (2014) examined the adaptation techniques of small farmers to climate change in Ethiopia. The study aimed to identify the factors that influence farmers' decisions to implement climate change adaptation measures and their preferences for different adaptation options. A questionnaire was used to collect primary data from 250 sample households, and analysis of the data using a logit econometric regression model revealed that farmer-to-farmer access to credit, farm size, number of animals kept, and advisory services increased the factors that significantly and positively influence farmers' decisions to adapt. However, farmland fertility and non-agricultural income have a negative and significant impact on farmers' climate change adaptation decisions. Agroforestry, shifting planting dates, soil and water conservation, small-scale irrigation, and temporary migration are the adaptation strategies employed by the farmers in Adola Rede, in order of most preferred to least preferred, according to the ROLM results. The ROLM show that institutional, socioeconomic, and demographic variables influenced the preferred adjustment.

In order to evaluate the rural population's knowledge about climate change and adaptation strategies, Solomon et al. (2016) conducted studies on environmental hazards related to climate change and variability and adaptation to climate change vulnerability in the lower basin of Lake Tana in Ethiopia. Heckman probit and multinomial logistic regression models showed that age, educational level, wealth status, agricultural extension services, and distance to the nearest health center emerged as significant predictors. The research is limited in that it does not explicitly state what tactics the farmers used.

In Bangladesh, Mohammed and Teshome (2015) examined the variables influencing farmers' methods of adapting to environmental degradation and the impacts of climate change at the farm level. The study examines how farmers have adapted to deteriorating environmental conditions likely to be caused or exacerbated by global climate change. In the study, self-reported ranking techniques were used to select the dominant approach and ordered regression was used to select the determinants. Of the eight categories examined, age, education, family size, farm size, family income, and participation in cooperatives were shown to be substantially related to self-reported adaptability.

In southwestern Nigeria, Otitoju and Enete (2014) conducted a study on agricultural efficiency and climate change adaptation techniques. The study used original information collected from 360 randomly selected farmers. The data were analyzed using the Cobb-Douglass stochastic marginal production model. The main techniques used by farmers to adapt to climate change included multiple cropping, land fragmentation, different planting dates, mulching and cover crops. While years of climate change knowledge and social capital showed significant negative associations with technical inefficiency, land fragmentation and different planting dates had strong positive associations. Similar insights into the impact of climate change on South African agriculture and available coping mechanisms were made by Benhin in 2006.

2.4.3. Impact of Climate Change Adaptation Strategies on Food Insecurity

A study by Ojo et al. (2022) on the impact of the adoption of climate change adaptation strategies on food security used an endogenous switching regression model and found a significant positive effect of adaptation on food security. They further argue that since impact evaluation studies frequently neglect to take into account potential differences in the characteristics between the two groups, a simple significant difference in the average number of adaptation strategies between adopters and non-adopters of climate change adaptation strategies in impact evaluation studies could be ambiguous. Direct coefficients from the model cannot be taken into account as ATT due to concerns with missing data (counterfactual scenario) if not accounted for. In a similar vein, even if endogeneity is taken into account, the estimate from the ESP model may still be inconsistent, if not misleading.

Amare and Simane (2018) used PSM method to study the impact of adoption of adaptation strategies on food security. The results show that gender, family size, access to counseling services, land holding size, and the frequency of droughts and floods have positively influenced the choice of adaptation options in recent years. The results further show that farmers who adopted one of the adaptation options had higher daily food calorie intake per adult equivalent than those who did not. By applying the endogenous two-step regression technique, Di Falco et al. (2011) examined the effects of adaptation on wheat productivity and its consequent impact on food security and found that adaptations to climate change positively and significantly affected wheat productivity, which in turn would help achieve household food security.

Demeke et al. (2011) used farm-household-level panel data from rural Ethiopia to examine the impact of rainfall shocks on household food security. This study constructed a time-varying food security index (FSI) using different combinations of food security indicators and application of PCA. Based on FSI, households were divided into relative food security groups and their determinants were assessed using a fixed effects instrument variable regression procedure. The paper highlighted the crucial role of precipitation variability in household food security, among a few other factors.

A study by Panganga-Phiri et al. (2012) also examined the impact of drought and flood adaptation on agricultural crop production and food security in Malawi. This study assumes that a household is considered food insecure if the grain availability per person per year is less than 300 kg. As such, the study ignores the other components of food security as well as the endogeneity of agriculture's adaptations to climate change.

2.5. Conceptual Framework of the Study

The interplay between climate change knowledge, choice of climate change adaptation strategies and household food security constitutes a complex, interrelated, and cyclical phenomenon that necessitates a sophisticated understanding. This thesis adopts a semi-sequential conceptual framework to elucidate these dynamics, particularly within the context of developing countries such as Ethiopia, where approximately 85% of the population resides in rural areas and relies heavily on agriculture for subsistence. The multifaceted nature of these challenges calls for a comprehensive examination of the underlying factors contributing to agricultural insecurity and food vulnerability.

The impact of climate change and variability on agricultural systems is profound and multifaceted. In Ethiopia, a confluence of interconnected factors exacerbates the challenges faced by rural households. These include population pressure, inadequate understanding of climate change impacts, ineffective agricultural policies, global climate fluctuations, cropland degradation, and insufficient market infrastructure. Collectively, these elements create a precarious environment that undermines food security, compromising agricultural productivity and heightening vulnerability among farming communities.

The relationship between climate shocks and food insecurity can be characterized as a vicious cycle. Climate change-induced shocks—such as droughts, floods, and erratic weather patterns—directly diminish crop yields and livestock productivity, thereby reducing household food availability. This decline in food security often precipitates a downward spiral into poverty, as households are compelled to deplete their resources to meet immediate needs. Consequently, the severity of this cycle not only impacts current food security status but also exacerbates future vulnerabilities, perpetuating a cycle of poverty and food insecurity.

Understanding the impacts of climate change and variability on food security is paramount for developing effective response strategies. Knowledge of these impacts informs the selection of appropriate adaptation strategies, which are critical for enhancing resilience among vulnerable populations. As noted by Tesfaye (2017), the capacity to adapt to climate-related challenges is influenced by various factors, including access to information, resources, and support systems. The choice of adaptation strategies is influenced by a myriad of factors, including socio-economic status, access to technology, and the availability of information regarding climate risks. Households that are well-informed about climate change and its potential impacts are more likely to adopt proactive measures to mitigate risks. These strategies may encompass diversifying livelihoods, implementing soil and water conservation techniques, engaging in small-scale irrigation practices, and utilizing climate-resilient agricultural inputs and practices. Furthermore, the effectiveness of these adaptation strategies is contingent upon the support provided by governmental and non-governmental organizations. Policies that promote access to resources, training, and financial assistance are essential for empowering farmers to implement effective adaptation measures.

The interplay between climate change knowledge and adaptation strategies significantly impacts household food security, which is determined by the availability, access, utilization, and stability of food resources. Households that effectively integrate climate knowledge into their adaptation strategies are more likely to attain food security through heightened agricultural productivity and resilience. In contrast, those lacking adequate knowledge or relying solely on reactive adaptation strategies may confront heightened food insecurity, particularly in the face of climate shocks. Thus, promoting climate literacy and supporting the adoption of effective adaptation strategies are crucial for improving food security and ensuring the sustainability of agricultural systems amidst climate variability.

The conceptual framework presented in this study highlights the intricate relationships between climate change knowlege, adaptation strategies, and food insecurity within the Ethiopian context. By acknowledging the cyclical nature of these challenges, this research aims to deepen our understanding of the factors influencing household knowledge of climate change impacts, the choices of adaptation strategies, and overall household food security status. Furthermore, the study explores the connections among household climate change knowledge, the selection of adaptation strategies, and food security in the study area. The following conceptual framework indicates the factors determining the adoption of climate change strategies, knowledge about climate change and the interplay between climate adaptation strategies, knowledge about climate change, and food security at household level.

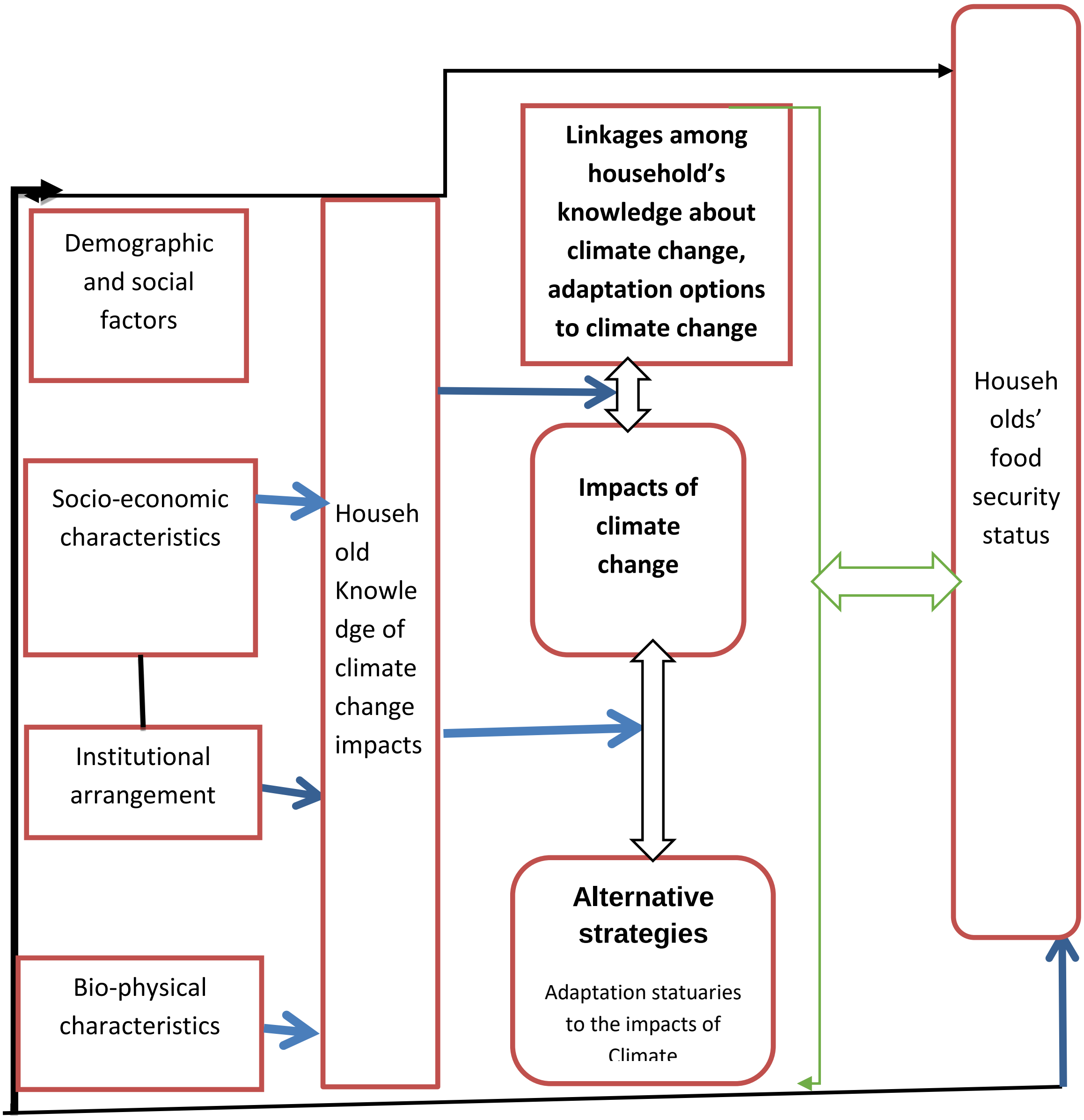

Figure 2: Conceptual framework of the study

Source: Researcher construction based on literature

3. RESEARCH METHODOLOGY

In this chapter, details of the methodology used to address the objectives of the study are presented. These include a description of the study area, population, sampling methods, and sampling size, data required and methods of data collection, methods of data analysis, and variables used for the study are presented in detail.

3.1. Description of the Study Area

The study was conducted in the Dire Dawa City Administration (DDA), astronomically situated between 9° 27' and 9° 49' N and 41° 38' and 42° 19' E. It is situated in the Eastern portion of Ethiopia, 515 km from the capital of Ethiopia, Addis Ababa, and 330 km to the west of the republic of Djibouti. The area has four clusters in 38 rural and nine urban kebeles (Smallest administrative units) that make up Dire Dawa City Administration.

Geographically, the area has rugged and undulating mountainous topography ranging from 1,000 to 2,260 meter above sea level (masl.) with a total average annual rainfall ranging between 410 to 850 mm and extreme temperature ranging from 14.5 to 34.6°C. It covers a total area of 1332.62 square kilometers and an estimated total population of 377,000 (CSA, 2016). Agriculture (both crop and livestock production) is the main stay of the economy in the study area. Subsistence mixed farming constitutes 93% of the total farm households in the study area.

The area is one of the most climate change and variability-stricken areas that affected agricultural production, livelihood, food security, and poverty of the local population. Though the area is conducive for livestock and crop production, climate change and variability has negatively affected smallholder farmers' agricultural production and productivity and their sustainable livelihood activities in the area.

Literature indicates that cereal crops, pulse, and horticultural crop production as staple, chat as commercial crop, and livestock rearing are the most dominant agricultural economic activities in the area. Climate change is the most dominant environmental challenge affecting agricultural community's social, economic, and environmental sustainability. Metrological data records showed that reduction trend in rainfall distribution and temperature is increasing over time.

Furthermore, irregular rainfall distribution with frequent droughts are among the extreme events which are among the factors affecting critical food insecurity expressed in crop and livestock low productivity, loss due to drought causes pathogenic, and entomologic crop and animal disease.

Climate change and variability is becoming the most drivers causing poverty, food insecurity and unsuitable environmental, social, political, and economic instability in the area. During the recent past five decades, there was significant frequent and intensive drought and flood that negatively affected agricultural productivity and food security; hunger and loss of asset of the community due to the impact of climate change and variability. Specifically, there is great change in rainfall distribution and time of onset that affected crop production and productivity. Climate change is also affecting water streams distribution and status most rivers are dried in the area.

All the rural kebeles of the administration are included in PSNP being extremely moisture deficient and vulnerable to drought and famine. Subsistence mixed farming system (both crop and livestock production) constitutes 93% of the farm households in the study area. Crops such as cereals, pulses, horticulture and chat, and livestock rearing are the most dominant economic activities in the area. Since agriculture is not reliable due to the scarcity of rain, community members in the area are largely engaged in off/non-farm activities. In particular, local women are known to have predominantly practicing off/non-farm activities, especially the petty trading of grain, chat and fruits and vegetables thereby earning substantial income for the household.

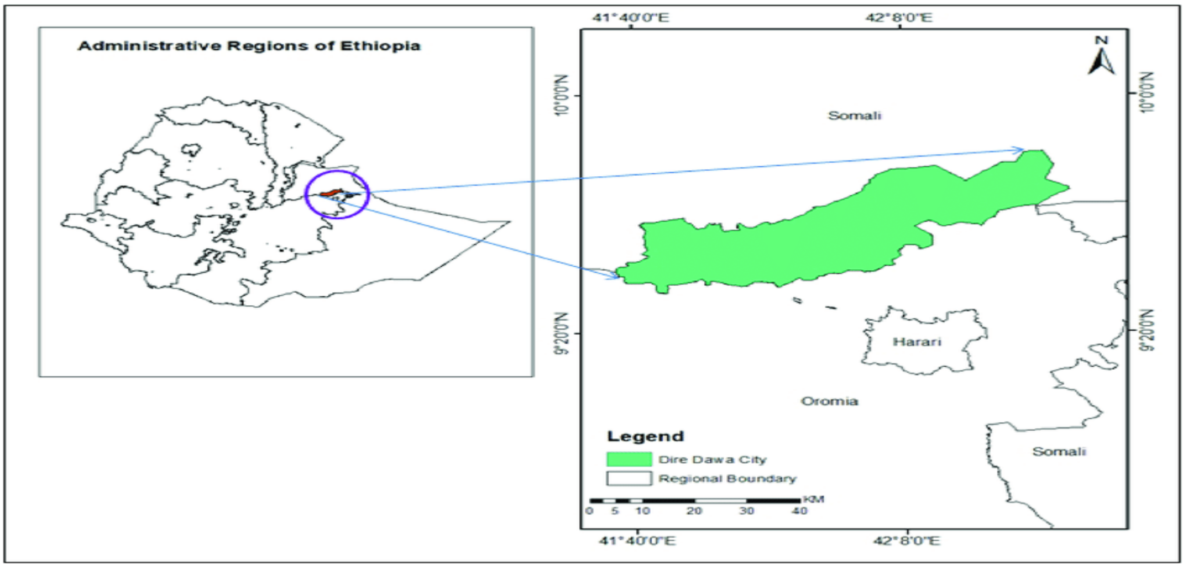

Figure 3: Map of the study area

3.2. Data Types, Sources and Methods of Collection

Primary and secondary data were used for this study. Primary data were collected by a team of skilled enumerators with previous experience in data collection, familiarity with the research area, and proficiency in the local language. Primary data were collected using a semi-structured questionnaire that was pre-tested and refined based on the feedback obtained from this exercise. Enumerators, who were recruited based on educational level and knowledge of the local language, were trained on the techniques of data collection, the contents of the questionnaire, and how to approach and convince households for the interview.

Key informants' interview (KII) was also made to complement data collected from farm households through interview schedules. Key informants were individuals selected from each sample *kebeles* and various organizations working in the study area. They were selected based on their indepth knowledge about climate change in the target area. Focus group discussions (FGDs) were also made with different community members like elders, religious leaders, women, youth, school heads at the local level, and agricultural experts. Focus group discussants were those who were not involved in the individual interview. Hence, one FGD and one KII were conducted at each *kebele* to enrich the primary data. Additionally, secondary data were collected from published and unpublished documents, reports from zonal and district offices of agriculture and natural resources for complementing primary data.

3.3. Sample Size and Sampling Techniques

The target population for this study is mixed farmers (crop producers and animal husbandry) and smallholder farm households of the Rural Dire Dawa City Administration. To study the population, representative sample farmers were selected, and economically efficient, reliable, and accurate data collection approaches were followed. Therefore, the research design meets these criteria to infer about the population under consideration using the optimum sample size selected.

3.3.1. Sample Size Determination

In social science research, there are different techniques to determine research sample size. The choice of sample size determination technique for each research depends on the nature of the population under consideration such as the size of the population, uniformity or heterogeneity, the nature and complexity of the objectives of the study, desired level of accuracy, available financial budget (logistics), time, level of expertise of the researcher, transportation facility, infrastructure, availability and utilization of digital technologies, culture and attitude of the community about personal data and research activities and so on. Since this study is academic research that has both financial (logistic) and time constraints, Kothari's (2014) sample size determination formula was employed:

$$n = \frac{z^2 pqN}{e^2(N-1) + z^2 pq} \tag{1}$$

Where: n is the sample size, Z is the standard cumulative distribution corresponding to the level of confidence, e is the desired level of precision (acceptable error), p is the estimated proportion of households exposed to climate knowledge, adaptation and food security, q = 1-p, and N is the population of rural farm households found in the Dire Dawa City Administration.

Accordingly, the sample size for the study is:

$$n = \left[\frac{(1.96^2)(0.5)(0.5)(12{,}098\ )}{(0.05^2)(12.97) + (1.96)^2(0.5)(0.5)}\right]$$

$$n = \frac{11618.92}{31.2029}$$

$$n = 372.36 \approx 372 \tag{2}$$

Based on the computation, out of the total farm households in all clusters, the sample size was 372 farm households. However, a 3.5 % contingency was used ‘as a result of the impact evaluation requiring a large sample size. Hence, a total of 385 sample households were selected and used with no missing respondents. Table 1 shows the study sample distribution in the study area.

3.3.2. Sampling Techniques

This study employed a multi-stage sampling approach, integrating both purposive and random sampling techniques to ensure a representative sample of smallholder farm households from the Dire Dawa Administration (DDA). This dual approach enhances the robustness and reliability of the findings, aligning with best practices in agricultural research.

In the first stage, purposive sampling was utilized to select the four rural clusters within the DDA. This technique is particularly effective when researchers aim to focus on specific characteristics or criteria relevant to the study. By intentionally selecting these clusters, the study ensures that the sample reflects areas that are most affected by climate change and agricultural challenges, thereby enabling a more nuanced understanding of the issues at hand. For instance, in a study by Adger et al. (2004), purposive sampling was employed to target communities that were particularly vulnerable to climate impacts. This approach allowed the researchers to gather in-depth insights into the adaptive strategies of those communities, which would have been overlooked in a purely random sampling framework.

Following the purposive selection of clusters, random sampling was applied to choose kebeles (administrative districts) within each cluster. Specifically, 15 kebeles were randomly selected—three from Jeldessa and four from each of the remaining clusters (Biyoawale, Aseliso, and Wahil)—based on probability proportional to the size of the kebeles. This method ensures that each kebele has a fair chance of being included in the sample, thereby reducing selection bias and enhancing the generalizability of the results. A similar approach was taken by Aklilu and Woldemariam (2016), who used random sampling to select households from different kebeles in Ethiopia to assess food security. Their findings demonstrated that random sampling effectively captured the diversity of experiences and challenges faced by households across various contexts, providing a comprehensive view of the issue.

Finally, a total of 385 farm households were selected using random sampling based on population size, as determined by Kothari's (2004) formula. This step is crucial as it ensures that the sample size is statistically valid and representative of the larger population of smallholder farmers in the selected kebeles. By employing probability proportional to population size, the study guarantees that larger kebeles contribute more households to the sample, reflecting their greater representation in the overall population. A combination of purposive and random sampling techniques in this study allows for a comprehensive understanding of climate change challenges faced by smallholder farmers in the Dire Dawa Administration. By purposefully selecting clusters that are most relevant to the research focus and randomly sampling kebeles to ensure representation, the study not only mitigated biases but also enhances the validity of its findings. This methodological rigor is essential for informing effective interventions and policies aimed at improving food security and resilience among smallholder farmers in the region.

Table 1: Distribution of sample farm households by clusters and Kebeles

Name of clusters	Name of Kebels	Households size	Sample size
Beyoawale FGD =3	Ijaaneni	739	33
	Legebira	650	29
	Adada	605	27
	Biyo Awale	672	30
	Total HHs in the cluster	**2666**	**119**
Aseliso FGD = 3	Hulahulul	426	19
	Haseliso	448	20
	Gedanser	515	22
	Goladen	403	18
	Total HHs in the cluster	**1792**	**79**
Jeledesa FGD=2	Mude Aneno	358	18
	Jeldesa	583	26
	Derba Agena	650	29
	Total HHs in the cluster	**1591**	**73**
Wahil FGD= 4	Harla	560	25
	Wahil	583	26
	Jelo Belina	650	29
	Legeoda Mirga	784	34
	Total HHs in the cluster	**2577**	**114**
	Total sample size	**8626**	**385**

Source: Dire Dawa Rural Administration Agricultural and Rural Development Office and own computation.

A total of 15 key informant interviews and 15 FGDs were conducted across the study areas. Key informants were selected based on their in-depth knowledge about climate change and the socioeconomic situation of the area. A total sample of 105 sample respondents (15 key informants and 90 focus group discussants) were selected purposively for the qualitative data. In-depth information about climate adaptation strategies, knowledge about climate change, and their interaction with food security were gathered using KII and FGDs.

3.4. Methods of Data Analysis

Before initiating the data analysis process, a thorough diagnostic assessment was conducted to evaluate the validity and reliability of the collected data, thereby adhering to rigorous standards of data quality and model fit. This research adopted a comprehensive analytical framework that integrates both descriptive and econometric techniques for the quantitative data analysis, employing STATA statistical software version 18 to ensure precision and robustness in the results. Concurrently, qualitative data gathered through Focus Group Discussions (FGDs) and Key Informant Interviews (KIIs) were analyzed using thematic analysis. By employing quantitative and qualitative methods, the study not only enriches the contextual understanding of the research issues but also enhances the overall validity of the findings through the triangulation of insights across both quantitative and qualitative dimensions, thereby contributing to a more nuanced understanding of the complex phenomena under investigation.

3.4.1 Qualitative Data Analysis

In this study, qualitative data obtained through Focus Group Discussions (FGDs) and Key Informant Interviews (KIIs) were analyzed using thematic analysis, a method that allows for the identification and interpretation of patterns or themes within qualitative data. This process began with transcribing the discussions and interviews verbatim to ensure accuracy and fidelity to the participants' voices. The transcripts were then systematically coded, where key concepts and recurring ideas were highlighted. These codes were subsequently grouped into broader themes that encapsulated the essential insights related to the research objectives. This thematic framework facilitated a structured understanding of the participants' perspectives on climate change adaptation strategies and food security challenges, allowing for a rich exploration of the complex dynamics at play in the Dire Dawa Administration.

To enhance the rigor of the analysis, the thematic analysis was complemented by a constant comparative method, which involved continuously comparing new data with existing themes to refine and expand the understanding of the issues discussed. This iterative process ensured that emerging themes were grounded in the data and reflected on the participants' experiences.

3.4.2. Descriptive Methods

In this study, different descriptive statistical tools such as ratio, mean, variance, standard deviation, percentage, frequency, and index were applied to describe farm households' climate change and variability knowledge, food insecurity status and choice of climate change adaptation strategies and their socio-economic, biophysical and institutional determinants in the study area.

In addition, bivariate analysis like t-tests, chi-square tests and correlation tests, multivariate F-test for continuous variables were used to make comparison of key variables used in the study.

3.4.3. Econometric Methods

As mentioned in the analytical review in Chapter 2, determinants of smallholder farm households' climate change knowledge were identified using Ordered Logistic Regression after a diagnostic test for model fitness. To identify factors influencing climate change adaptation strategies, Multivariate Probit Regression model was applied. Endogenous Switching Regression model was used to evaluate the impact of the adoption of climate change adaptation on household food security. Finally, the Trivariate Probit Seemingly Unrelated Regression model was used to evaluate the interlinkages between farmers' knowledge of climate change, choice of adaptation strategies, and food security in the study area. The specification of each model is given below.

3.4.2.1. Determinants of farmers' knowledge of climate change

To determine the factors affecting farmers' knowledge of climate change, it is important to understand the distribution of the dependent variable. This variable is ordered in nature assuming values from low knowledge to higher knowledge having four categories. In this study as in Zobeidi et al. (2020) knowledge about climate change is categorized into knowledge of causes with indicators (climate change is caused mostly by human activities and climate change is caused more or less equally by natural changes in the environment and human activities) and knowledge of consequences with four indicators (Climate change will increase the negative public health impacts, climate change will decrease the sea level, climate change will increase the droughts and climate change will increase the insects) both measured in five points Likert scale (1= Strongly disagree, to 5= Strongly agree). This gives a total score of 30 (100%). Following Musah et al. (2023), respondents were categorized into "very good-excellent or high" knowledge of climate change if they had a score of 90% and above, "adequate or medium" knowledge of climate change if they scored from 75 to 89%, "average" knowledge of climate change if they scored 50 to 74% and "inadequate" or "poor" knowledge on climate change if they scored below 50%.

As a result, the ordered logit model (OLM) was selected in this study to identify factors affecting smallholder farmers' knowledge of climate change impacts as in Williams (2016). The OLM is specified as follows:

$$P(y_i > j) = \frac{exp(\alpha_j - X_i\beta_j)}{1+exp(\alpha_j - X_i\beta_j)}, \quad j=1, 2\ldots J-1 \tag{3}$$

Where: y_i is the value of climate change knowledge level in the case of agriculture on categorical variables or scales. X_i is an explanatory variable including socio-economic, demographic, institutional, and physical characteristics of farmland; β_j is an $(m \times 1)$ vector of regression coefficients and α_j represents the cut-off point for the j^{th} cumulative logit.

The results from standard OLM are valid only when the proportional odds assumptions for parameter estimates are constant across the severity scores (Williams, 2016; Weisburd and Britt, 2014). Therefore, after the standard OLM regression fitness is verified, a formal Brant (1991) test was conducted and if the assumption is not violated the ordered logistic regression model was applied to identify factors affecting farmers' knowledge about the climate change and variability impacts.

3.4.2.2. Determinants of choice of adaptation strategies

Farm households use different strategies when they understand the impact of climate change negative impacts on their agricultural productivity and welfare. But climate change impacts and the understanding and farmers responses varies from location to location based on their social, economic, institutional, and biophysical factors.

The type (nature), relative complementarity or substitution of the choices and type of study determine the selection of the model to be used in identifying the determinants of adaptation (Haensel et al., 2011). As described in the analytical framework of the study in chapter 2, multivariate probit (MVP) was chosen as it captures the possible interdependence among the choices and that farmers can adopt multiple strategies. Failure to account for unobserved elements and the interdependence of adaptation decisions may result in inefficient and erroneous estimation (Greene, 2008). Farmers are more likely to embrace a package of climate change adaptation strategies that maximize their projected utility in dealing with a variety of climate change risks and restrictions than they are to adopt a single sustainable climate change adaptation activity.

Hence, the MVP model was used to identify the determinants of farmers' adaptation strategies and probable interrelationships between them. The usage of adaptation is based on the utility maximization paradigm, and the application of diverse adaptation strategies lowers the negative impact of climate change (Fadina and Dominique, 2018).

The MVP model is characterized by j binary adaptation strategies as dependent variables equations Y_{ij} such that:

$$Y_{ij}^{*} = \beta'_{j} x_i + \varepsilon_{ij} \quad j=1, 2\ldots M \qquad (4)$$

and

$$Y_{ij} = \begin{cases} 1 \; if \; Y_{ij}^{*} > 0 \\ 0 \; otherwise. \end{cases}$$

Where: Y_{ij} = 1 individual farm adopted an adaptation strategy under consideration. X_i is a vector of explanatory variables. β_1, β_2, β_3, β_4 and β_5 are parameters to be estimated and random error terms are ε_1,ε_2,ε_3,$\varepsilon_4$and ε_5 distributed as a multivariate distribution as zero mean and unitary variance that has a 5*5 contemporary correlation matrix $R = |\rho_{ij}|$ with density of ε_1,ε_2,ε_3,$\varepsilon_4$and ε_5 error terms.

$$Pr(y_1, y_2, y_3 \ldots y_5|x) = \int_{-\infty}^{(2y_1-1)x\beta_1'} \int_{-\infty}^{(2y_1--21)x\beta_2'} \int_{-\infty}^{(2y_1-3)x\beta_3'} \varphi(\varepsilon_1, \varepsilon_2, \ldots \varepsilon_5 : z' R z) d\varepsilon_2 d\varepsilon_1$$

Where $Z = diag(2y_1 - 1, \ldots 2y_5 - 1)$. (5)

The maximum likelihood estimation is used to maximizes the sample likelihood function, which is the product probability across the sample observation (Alemayehu and Bewket, 2016).

3.4.2.3. Impact of adaptation strategies on farm households' food security

The decision to adapt to climate change impacts depends on the farm household on the utility of adaptation such as food security or income that improves the welfare of the household head so that (U_{1i}) compared to no adaptation (U_{0i}). Farm household decides to adapt an adaptation strategy A_i if its utility = U_{1i}, is greater than the utility of non-adaptation $U_{0i}>0$, in accordance with Becerril and Abdulai's (2010) random utility decision-making model. Despite being unobservable, the utility difference can still be stated as a function of observable factors. The household decision equation for adoption of climate change strategy in the study area can be defined as:

$$A^*_i = z_i x + \mu_i, \text{ if } A^*_i > 0, \text{ then } A_i = 1, \text{ otherwise } A_i = 0 \quad (6)$$

Adaptation; z_i is the exogenous explanatory variable, that affects the farm household's choice of adapt adaptations strategy; μ_i is the random disturbance term. Farm management performance model can be defined as follows in order to measure the impact of adaptation strategies to climate change stresses on food security:

$$Y_i = X_i \beta_i + \delta A_i + \varepsilon_i \quad (6)$$

In Eq (6), Y_i is the indicator of farm household food security during the survey period; X_i is the vector of individual farm households and farm characteristics (such as age, education, family size, farm size, etc.) that may affect farm performance indicators; A_i is whether the farmer i adopt any of the adaptation strategies or not; ε_i is a random disturbance term. In view of the fact that a household choose whether to adapt or not to the impact of climate change according to their own conditions, the decision-maker's adaptation strategy (A_i) may be affected by some unobservable factors, which are related to the outcome variable (Y_i). This leads to the correlation between A_i and ε_i in Eq (6).

As a consequence, the direct estimation of Eq (6) may lead to estimation errors due to the problem of sample self-selection. As mentioned before, the endogenous switching probit regression (ESPR) model has certain advantages in solving the problem of endogeneity and comprehensively considering observable and unobservable factors, and can effectively avoid the "invisible bias" caused by unobservable factors. Therefore, this study used the ESPR model to examine the impact of adaptation of strategies on farm households' food security status.

The ESPR model is divided into two stages. The first stage is to use the probit model to estimate whether the farm household adopts an adaptation strategy (selection equation), as shown in Eq (7); the second stage is to establish the farm household food security determination equation and estimate changes in food security caused by the adaptation strategies. The performance models of household with and without adaptation strategies respectively are specified as follows:

$$Y_{Ai} = X_{Ai}\beta_{Ai} + \delta_{\mu Ai}\lambda_{Ai} + \varepsilon_{Ai}, if \;\; A_i = 1 \tag{7}$$

$$Y_{ni} = X_{ni}\beta_{ni} + \delta_{\mu ni}\lambda_{ni} + \varepsilon_{ni}, if \;\; A_i = o \tag{8}$$

In Eqs (7) and (8), Y_{Ai} and Y_{ni} respectively refer to the level of household food security with and without adaptation of any climate change adaptation strategies. In addition, X_{ia} and X_{in} indicate the factors that affect the food security of the two types of farm households; ε_{ia} and ε_{in} both represent random disturbance terms. The correlation coefficients of ε_{ia}, ε_{in} and μ_i were 1 and 0, respectively.

This work introduces the inverse Mills ratio λ_{ia}, λ_{in} and their covariance in order to solve the problem of sample selectivity bias caused by unobservable factors. In addition, it uses the complete information maximum likelihood method to estimate equations (5), (7) and (8) simultaneously. After the estimated parameters are obtained, the net impact of adoption of adaptation strategy/ies to climate change stresses, that is, the average treatment effect of adaptation on the farm household food security is obtained as follows.

Treatment effect estimation

By comparing the expected value of farm household food security effect/impact of the adaptation, average effect food security of climate change adaptation decision. Expected food security status using adaptation practices is given by:

$$E(Y_{ia}|A_i = 0| = X_{ia}\beta_a + \delta_{ua}\lambda_{ia} \quad (9)$$

Expected adaptation impact on food security of farm households who did not adopt any adaptation strategy is given by:

$$E(Y_{in}|A_i = 0| = X_{in}\beta_n + \delta_{un}\lambda_{in} \quad (10)$$

In the meanwhile, consider two counterfactual assumptions, that is, the expected operating effect of food security of a farm household using adaptation without adaptation:

$$E(Y_{in}|A_i = 1| = X_{ia}\beta_n + \delta_{un}\lambda_{ia} \quad (11)$$

Through formulas (8) and (9), it is obtained that the average adaptation treatment effect of farm operating food security od adaptation is as follows:

$$ATT = E(Y_{in}|A_i = 1| - E[Y_{in}|A_i = 1|) = X_{ia}(\beta_a - \beta_n) + (\delta_{\mu a} - \mu_{un})\lambda ia \quad (12)$$

Similarly, the average treatment effect of operating income from family farms without new technologies is:

$$ATU = E(Y_{in}|A_i = 1| - E[Y_{in}|A_i = 0|) = X_{ia}(\beta_a - \beta_n) + (\delta_{\mu a} - \mu_{un})\lambda in \quad (13)$$

3.4.2.4. Linkages among knowledge of climate change, adaptation strategies and food security

This sub-section discusses the interdependence of the results among the production among farmers' knowledge of climate change, adaptation of adaptation strategies, and food security. A priori, one would expect a household to have good knowledge about climate change impacts is related to the decision to adopt adaptation strategies which will significantly influence whether or not the household has improved its food security situation (Tadesse and Alemayehu, 2019). To capture this multivariate interdependence among farmers' knowledge of climate change, adaptation of adaptation strategies is simulated with the explanatory variables. Consequently, the households' food security is assumed to be interdependent with farmers' knowledge of climate change, and adaptation of adaptation strategies. This interdependence was simulated by the Seemingly Unrelated Regression (SUR) model.

Thus, to examine the interaction among farmers knowledge of climate change, adaptation strategies, the impact of adaptation strategies on food security using a simulated maximum likelihood estimation Trivariate SUR:

$$kCCI_i = x'_1\beta_1 + e_{1i}$$
$$Fis_i = x'_2\beta_2 + e_{2i}$$
$$Ad_i = x'_3\beta_3 + e_{3i} \qquad (14)$$

Where KCl_i–farmers knowledge of climate change FS_i–food security status and Ad_i – adaptation of household i respectively. $\beta's$are parameters of interest with the dimension of $kx1$and $e_i$is $gx1$dimension of the unobservable error terms. The assumption of error terms to be strictly exogenous, homoscedastic, nonzero correlation among equations but zero correlation among observations. The three equations are often called seemingly unrelated regressions (SUR) model after Zellner (1962) work for cross sectional data.

The simulated maximum likelihood estimator has a wide range of desirable properties. The simulated probabilities are unbiased, they are bounded within the (0, 1) interval, and it is a continuous and differentiable function of the models' parameters. It is also more efficient in terms of the variance of the estimator probabilities.

Test for multicollinearity

Prior to the estimation of the model parameters, a multicollinearity test was conducted among potential hypothesized independent variables to make unbiased estimation using Variance Inflation Factor (VIF). According to Gujarati (2004), VIF can be defined as: VIF (X_i) = $\frac{1}{1 - R_i^{2}}$

Where R_i^2 is the coefficient of determination when the variable X_i is regressed on the other explanatory variables.

3.5. Variables Definition and Hypothesis

3.5.1. Determinants of Farmers' Knowledge of Climate Change Impacts

Dependent variable: Farm household's knowledge of climate change impacts refers to the level of knowledge that farmers have about the impacts of climate change. It was measured on a four Likert scale as indicated above: Poor (1), Average (2), Adequate (3), and very good (4).

Independent variables: Independent variables, their measurement, and hypothesized relationships are set based on the review of literature in the respective econometric models.

The hypothesized relationship between the dependent variable (household knowledge level) and the independent variables is described below and summarized in Table 2.

Sex of the household head: It is a dummy variable that assumes a value of 1 if the household head is male and 0 if female. Compared to female household heads, male household heads are more knowledgeable about the effect of climate change and variability on agricultural performance because of the cultural and religious background of most African communities in general and the local community in particular that still put women's enterprise under their husbands' care as a form of submission (Bamire et al., 2010). Therefore, sex is hypothesized to affect knowledge about the impacts of climate change positively and significantly.

Age of the household head: It is a continuous variable measuring the age of the household head in years. Different literature shows that the higher the age of the farm household head, the more they have experience and understanding of the adverse effects of climate change and variability. Therefore, age is hypothesized to positively correlate with the higher degree of farmer's knowledge about the climate change impact and associated problems (Bekele and Drake, 2003).

Family size: Family size is a continuous variable measured by the number of members of the household. It is assumed to represent the labor input to the farm. It is assumed that large family members strive much to feed themselves and are highly likely to search for information about climate change which adversely affects food production. In this study, therefore, the family size is assumed to have a positive effect on farmers' knowledge about climate change impacts (Bekele and Drake, 2003).

Education level of the household head: Is continuous variable refers to the farm household head's educational attainment level in years of schooling. The educational level of the farm household head is useful to know the current and past situations of climate change and variability problems. It has a crucial role in increasing information about environmental problems in general and the causes and consequences of climate-induced shocks in particular (Shibru et al., 2023). Therefore, education level is hypothesized to affect knowledge about the impacts of climate change positively and significantly.

Marital status of the household head: It is a nominal variable. Marital status has an important bearing on the size and structure of families and households are categorized as married and unmarried (divorced, widowed, and single). Farm household head's marital status has a strong relationship with the knowledge of the existing environmental degradation due to climate change. Married household heads have better climate change and variability knowledge, because as soon as they are married, they need productive and large farm size for the next life (Muluneh, 2003).

Extension contact: Is a continuous variable measured in the farm household head's number of contacts with development agents during the survey year. Extension contact will provide farmers with information on the adverse impact of climate change on crop production and productivity and their food security status and hence positively affect farmers' knowledge about the impacts of climate change. This hypothesis is supported by the study of Shibru et al. (2023).

Farm income: It is a continuous variable that refers to a household's annual income from agricultural activities in Birr. It is believed to reflect previous achievements of the farm households and their ability to accept risks. Thus, households generating better farm income are better placed to search for information about the impacts of climate change and know climate change effects better than others. Therefore, farm income is likely to be positively related to farmers' knowledge about the adverse effects of climate change and variability.

Social participation: It is a dummy variable that measured in participation of the households in different social occasions (Iddir, Iqub, etc) and has access to information on the adverse impacts of climate change and how to tackle it (Shibru et al., 2023). If the household is participating in such social activity, it is 1 otherwise 0. This variable is hypothesized to influence farmers' knowledge of climate change impacts positively.

Farm size: It is a continuous variable measured in hectares. It refers to the area of the farmland in hectares owned by the household. The larger the field, the higher is the likelihood of witnessing rills, surface runoff, sediment deposition and redeposit by farmers as effects of climate change (Bewket and Sterk, 2002). Larger parcel sizes may create a positive incentive for small-scale farmers to invest in SWC technologies by realizing the adverse effects of climate change (Tesfaye et al., 2014b; Teshome et al., 2016). It is expected that the larger the farm size that the farmer owns the higher the intensity of knowledge about climate change.

Livestock owned: It is a continuous variable measured in tropical livestock unit (TLU). A farm household who has large livestock unit can easily observe and develop knowledge of climate change as climate change affects livestock feed supply and causes different diseases to their livestock. Therefore, a positive sign is expected with knowledge about climate change (Bewket and Sterk, 2002; Kassie et al., 2009).

Access to credit: Access to credit service is a dummy variable represented by 1 for a household who had access to credit and 0 otherwise. Access to credit was hypothesized to play a significant role in enhancing farmers' knowledge of climate change. This is because farmers who have access to credit should pursue different information as returning the credit might be influenced by different factors including climate change and hence are more aware of climate change compared to others. A study by Zemenu and Minale (2014) on credit services for farm inputs and consumption found that credit access could increase awareness and the adaptation of conservation measures by farmers.

Access to climate change information: It is a dummy variable measured by the accessibility of the information which is represented by 1 if the household has access to the climate change information otherwise 0. Availing accurate information on climate change is not an easy task. The presence of well-functioning weather stations proper processing of weather data and dissemination of weather forecasts as well as acceptance of the information by users is assumed to influence knowledge of climate change positively (Belay et al., 2017). Therefore, this variable is hypothesized to influence the dependent variable positively

Land fragmentation: It is a discrete type variable measured in a number of plots. This refers to the number of farm plots that the household head owns. It is hypothesized to have a significant negative effect on climate change knowledge due to high transaction and management costs associated with fragmented farmlands compared to others. This is in line with the results of Tran and Vu (2021) who argue that land fragmentation adversely affects farm production because fragmentation not only prevents farmers from using modern, mechanized equipment, such as tractors and harvesters but also prevents the adoption of high-value crops that can only be cultivated on a large scale.

Market distance: Market distance is a continuous variable measured in kilometers, representing the distance from a farm household's residence to the nearest market. As the distance increases, so do the transactional costs associated with accessing climate change-related information. Consequently, greater market distance negatively impacts households' knowledge about the effects of climate change. This hypothesis is supported by the findings of Asaye et al. (2021).

Table 2: Summary of variables affecting households' knowledge of climate change

Variable Name	Type of variable	Measurement	Expected Sign
Dependent variable			
Farmers' knowledge of climate change	Ordered	1= Poor (<50%) 2= Average (50%≤x<70%) 3= Adequate(70%≤x<90%) 4= Very good (≥90%)	
Independent variables			
Age	Continuous	Years	+/-
Sex	Dummy	1= Male, 0= Female	+
Education level	Continuous	Years of schooling	+
Marital status	Dummy	1= Married, 0= Unmarried	+
Extension contact	Continuous	Number of contacts per annum	+
Farm size	Continuous	The size of the farm land owned by the household in hectares	+
Family size	Continuous	Number of members of the family	+
Livestock owned	Continuous	Tropical livestock unit	+

Access to credit	Dummy	1= Yes, 0= No	+
Access to climate information	Dummy	1=Yes, 0=No	+
Social participation	Dummy	1=Yes, 0=No	+
Land fragmentation	Continuous	Number of plots	-
Market distance	Continuous	Distance to the nearest market in km	-

3.5.2. Determinants of Choice of Adaptation Strategies

Dependent variables: It is a categorical variable represented by Y_1=Livelihood diversification, Y2=Soil and water conservation, Y_3= Chemical fertilizer, and Y_4=Irrigation. Adaption strategies are used to moderate the impact of climate change and variability that varies in space and time. Literature review result shows that farm households use different climate adaptation strategies which include livelihood diversification, multiple cropping, timely planting, using different and new crop varieties, increased livestock production, irrigation development, soil and water conservation, increased farmland, and increased training. In this study, the selection of the most important adaptation strategies was made based on FGDs with DAs, community leaders, and some selected farmers. Each option was arranged based on the preferences in order of importance without ties. Accordingly, the four most adopted adaptation strategies are identified. These are livelihood diversification, soil and water conservation, chemical fertilizers, and small-scale irrigation.

Independent variables: The choice of independent variables used in this study was determined by the literature review on factors that influence farmers' decisions to what type of adaptation strategies they pursue to withstand the vagaries of climate change and variability. Based on this, the following variables were hypothesized to affect the adoption of climate change adaptation strategies.

Sex of the household head: It is a dummy variable that assumes a value of 1 for male-headed households and 0 otherwise. Male household heads are expected to adopt different adaption strategies more than female household heads, because of the cultural bias towards them, in Africa in general and in Ethiopia in particular. Males are more empowered than females in social, economic, skill and farming which affects the adoption and selection of adaptation strategies (Nhemachena and Hassan, 2007).

According to Belay et al. (2017) male headed households could be more likely to have access to technologies and climate change information than female-headed households and as a result, they were in a better position to practice diverse adaptation strategies than their male counterparts.

Age of the household head: It is a continuous variable measured in years. The age of the household head can be used to capture the farming experience and its influence on adaptation to the impact of climate change. For example, Obayelu et al. (2014) in their study of factors affecting farmers' choices and adaptation strategies to climate change in Nigeria reported that age has a positive influence on farmer's efforts to adapt to climate change. Similar views were also expressed on the effect of age on an adaptation of improved agricultural technologies by Gbegeh and Akubuilo (2012). Therefore, the age of the household head influences adoption of the less labor-intensive adaption strategies, for instance, the decision to intensify agricultural inputs (Belay et al., 2017).

Marital status of the household head: Marital status is a categorical variable that has an important bearing on the size and structure of families and households are categorized into married, divorced, widowed, and single. Farm household head's marital status has a strong relationship with the knowledge of the existing environmental degradation due to climate change. Married household heads have a higher probability of adopting adaptation strategies because they can support each other as these strategies are labor-intensive in most cases. Hence, marital status (being married) influences the adoption of climate change adaptation strategies positively (Hassan and Nhemachena, 2008).

Educational level of the household head: Education is a continuous variable measured in Grade level completed by the household head. The Grade level completed by the household head is used as a proxy for managerial input. Education plays an important role in the adaptation of innovations/new technologies. Maddison (2006) argued that education diminishes the probability that no adaptation is taken. Therefore, in this study, education level is hypothesized to be positively and significantly influencing farmers' choice of diverse adaption strategies in order of importance.

Family size: Family size is a continuous variable measured by the number of members in a household/ adult equivalent. It is assumed to represent the labor input to the farm. Mano and Nhemachena (2006) contended that large household sizes are most inclined to divert part of its labor force into non-farming activities. Gbetibouo (2009) reported that household size enhances the farmers' adaptive capacity to respond to climate change if the adaptive strategies are labor-intensive. In this study, therefore, the variable is assumed to have positive or negative impacts on climate adaptations.

Farm size: It is a continuous variable that refers to the area of the farm land in hectares owned by the household. The larger the field, the higher is the likelihood of witnessing rills, surface runoff, sediment deposition and redeposit by farmers as effects of climate change (Bewket and Sterk, 2002). Larger parcel sizes may create a positive incentive for small-scale farmers to invest in SWC technologies by realizing the adverse effects of climate change (Tesfaye et al., 2014b; Teshome et al., 2016). It is expected that the larger the farm size that the farmer owns the higher the likelihood of adopting climate change adaptation strategies.

Farm income: It is a continuous variable that refers to a household's annual income from agricultural activities in Birr. It is believed to reflect previous achievements of the farm households and their ability to accept risks. Thus, households generating better farm income are better placed to adapt because of their improved adaptive capacity (Shiferaw and Holden, 1998). Therefore, farm income is likely to be positively related to climate change and variability adaptation.

Extension contact: It is a continuous variable refers to the number of contacts that the household head made with extension agents during the survey year. Most studies have documented positive relationship between extension contact and adaptation decision of farmers (Shongwe et al., 2014) as agricultural extension contact is an important source of information, and advice and provision of technical supports (extension services) to smallholder farmers in Ethiopia which will increase farmers' knowledge, skills and awareness towards new innovations. Therefore, extension contact is hypothesized to influence farmers' adaptation to climate change and variability positively.

Market Distance: This is a continuous variable indicating the distance from a farm household's residence to the nearest market, measured in kilometers. As the distance from the market increases, the transactional costs associated with accessing climate change-related information also rise. Consequently, greater market distance negatively impacts the adoption of climate change adaptation strategies. This hypothesis is supported by the findings of Asaye et al. (2021).

Distance to road: It is a continuous refers to the distance of the farm household's residence from the main road in kilometers. The higher is the distance of the main road from the farm household's residence the higher is the transactional costs of getting climate change-related information, reduced market access, inefficient delivery of farm inputs and increased transportation costs (Wudad et al., 2021).

Access to credit: The use of credit from microfinance and other sources measured by dummy variables whether used or not and credit service is an important factor in narrowing the financial gap of the farmers so that they can purchase the required farm inputs and technologies that are useful for improving agricultural production and also to carry out income generating activities other than farming (Komba and Muchapondwa, 2015). This variable is therefore assumed to influence farmers' adaptation to climate change and variability either positively or negatively.

Perceived productivity: This refers to farm households' perception about the productivity differential due to adoption of adaptation strategy/ies. It is a dummy variable that assumes a value of 1 if the household head has a positive perception, otherwise 0. Households having positive perceptions about productivity enhancement of a strategy adopt it easily compared to others. This variable is therefore assumed to influence farmers' choice of adaptation strategies positively (Telewold et al., 2017).

Livestock owned: It is a continuous variable measured in tropical livestock unit (TLU). A farm household that has a large livestock unit can easily observe and develop knowledge of climate change as climate change affects livestock feed supply and causes different diseases to their livestock. Therefore, a positive sign is expected with the choice of adaptation strategies (Bewket and Sterk, 2002; Kassie et al., 2009).

Land fragmentation: It is a continuous variable that refers to the number of farm plots that the household head owns. It is hypothesized to have a significant negative effect on climate change adaptation strategies due to high transaction and management costs associated with fragmented farmlands compared to others. This is in line with the results of Tran and Vu (2021) who argue that land fragmentation adversely affects farm production because fragmentation not only prevents farmers from using modern, mechanized equipment, such as tractors and harvesters but also prevents the adoption of high value crops that can only be cultivated on a large scale.

Table 3: Summary of the variables, types, measurement unit, and expected sign and adaption strategies

Variables	Types	Measurement	Hypothesis
Dependent variable			
Adaptation strategies	Nominal	1=Livelihood diversification, 2=Soil and water conservation, 3= Chemical fertilizer, 4=Irrigation	
Independent variables			
Sex	Dummy	1 if male and 0 otherwise	+
Age	Continuous	Years	+/-
Farm experience	Continuous	Years	+
Education level	Continuous	Grade level completed	+
Family size	Continuous	Number of family members	+
Farm income	Continuous	Annual farm income in Birr	+
Extension contact	Continuous	Number of contacts per year	+
Distance to road	Continuous	Distance to the main road in km	-
Distance to market	Continuous	Distance to the nearest market in km	-
Farm size	Continuous	Size of the farm land in hectare	+
Land fragmentation	Continuous	Number of plots	+/-
Access to credit	Dummy	Yes=1, No=0	+

Perceived productivity	Dummy	1 if the household has a positive perception, 0 otherwise	+
Livestock owned	Continuous	TLU	+

3.5.3. Impact of Adoption of Adaptation Strategies on Food Security

Dependent variable

Adaptation status of the farm household: It assumes a value of 1 if the household adopts at least one of the above-mentioned climate adaptation strategies and 0 otherwise.

Outcome variable

Food security: It refers to the food security score of the household measured in kilocalories per AE per day. This is a dummy variable taking the value of 1 for households consuming more than 2550 kilo calorie per day per adult equivalent while households consuming less than 2550 kilo calorie per adult equivalent per day are considered as food insecure.

Independent variables

From the review of theoretical and empirical kinds of literature, the following variables are assumed to affect food security and adaptation at the same time.

Age of the household head: It is a continuous variable that describes the age in years of the household head. Adaptation, the production process (selection, production, storage, processing, and marketing), and the source of income are all significantly influenced by age. Older farmers can benefit much from their long-established traditional agricultural practices, but they are anticipated to be less receptive to recently introduced innovations, such as enterprise/technology. In other words, it is assumed that as people get older, they become more conservative and less flexible compared to younger people, and as a result, they are less likely to engage in adaptation, are less productive, and earn less money for their families. Younger and middle-aged farmers are highly likely to adopt adaptation strategies compared to older farmers (Damisa et al., 2007). Thus, age is hypothesized to have a negative influence on the decision to adopt adaptation strategies and food security.

Sex of the household head: It is a dummy variable that assumes a value of 1 for the male household head and 0 otherwise. It is hypothesized that male-headed households are more adapters to reduce climate change-related impacts including food security as compared to female-headed households. This is because female-headed households have additional roles of reproductive and home-based management activities. Social, economic, political and cultural aspects of most developing countries motivate male than female in developing capacities in every aspect of livelihood including agricultural practices (Mihiretu et al., 2020). Therefore, male-headed households adapt more to climate change and ensure food security.

Education level of the household head: It is a continuous variable that refers to Grade level completed by a household head of family. Farmers' perception, interpretation, and reaction to climate change in the context of risk are improved by his/her formal education. Reading and writing skills are intended to provide farmers with a leg up when it comes to learning about and appreciating the advantages of using agricultural technologies (Mihiretu et al., 2020). Therefore, education was hypothesized to positively and significantly affect adaptation and food security.

Family size: It is number of people living in a household as a whole. Farmer's decision about adoption of adaptation practices to the impact of climate change is influenced by family size as it is influenced by the availability of labor or erodes adaptive capacity if the majority of the family members are economically dependent, children or aged people (Belay and Mengiste, 2021). Adaptation to climate change impacts raises the seasonal demand for labor (particularly for seed production, management, and post-harvest handling); making it more desirable for households with a high number of family members to participate because these families have economically useful labor. However, if the technology supports adaptations that require adaptive capacity to replace tools like weed killers and combiners in harvesting, it may result in a reduction in the need for human labor. Therefore, it is expected that the family/household size affects positively or negatively the likelihood of adaptation to the impact of climate change and improves food security.

Farm size: It is a continuous variable and represents the total owned and cultivated land (in hectares) by the farm household. Land is the key asset and the primary source of livelihood for all rural households especially in the agricultural sector. Many agricultural activities require substantial productive economic resources of which land is the principal one. Farm activities require primarily the availability of suitable farmland. Households with larger cultivated land are more willing to participate in different crops and livestock production and allocate a better proportion of land as compared to farmers with small farm sizes. Large farm is often correlated with farm income and wealth (if well managed and utilized), and can ease the liquidity constraints to participate in the adoption of innovations. Hence, this explanatory variable is hypothesized to positively and significantly influence the decision to adopt adaptation strategies to the impact of climate change and food security. Previous research results reported by Thomas and Fanaye (2012) also indicated that farm size was positively and significantly related to technology adaptation.

Extension contact: It is a continuous variable that represents the number of contacts the respondent had with extension agents during the survey year. The primary source of agricultural information, knowledge, guidance, and practices for smallholder farmers in Ethiopia is thought to be a development agent. The use of agricultural technologies by farm households is influenced by DA interaction as a source of information (Mihiretu et al., 2020). Farmers who interact with development agents frequently (at least once per week or more frequently) tend to have better access to climate change information, diverse agricultural practices, diverse improved livelihood and climate, and consequential information that help better understanding and have knowledge, and are anticipated to adapt quickly than farmers who do not have similar opportunities. Therefore, it was hypothesized that contact with development agents increases the likelihood of adapting to climate change impacts and improves food security status.

Climate information: This is a dummy variable that refers to whether the household head has access to climate information from mass media or not, and takes the value of 1 for those who have access to climate information, otherwise 0. In order to get current information on local climate change impacts on agricultural activities, accessibility to and use of radio, television, written materials developed in local languages, and public meetings at all levels will be taken into consideration. Farmers can get climate information from a variety of sources media being one of them. If knowledge is effectively disseminated through mass media and other platforms, the attempt to distribute new innovations is largely successful (Keba, 2019). Therefore, it is hypothesized that household heads' exposures to climate change information have a considerable positive impact on their decision to embrace agricultural technologies and increase their income.

Access to credit services: It is a dummy variable whether the farm household uses credit services or not. Financial services might help households become more risk-tolerant and encourage them or improve their adaptive capacity or adaptability of farm households. It was anticipated that farmers who utilized financial credit would have an advantage over those who did not adapt to climate change impacts (Mihiretu et al., 2020). It was therefore hypothesized that the use of credit facilitates household adaptation and food security status.

Social participation: It is a dummy variable that shows households participating in different social occasions (Iddir, Iqub, etc) have access to information on the adverse impacts of climate change and how to tackle it (Shibru et al., 2023). This variable is hypothesized to have positive effects on farmers' adoption of climate change adaptation strategies and food security status positively.

Livestock owned: It is a continuous variable measured in tropical livestock unit (TLU). A farm household that has a large livestock unit can easily observe and develop knowledge of climate change as climate change affects livestock feed supply and causes different diseases to their livestock. Therefore, a positive sign is expected with the adoption of climate change adaptation strategies and food security status (Bewket and Sterk, 2002; Kassie et al., 2009).

Market distance: This is a continuous variable that refers to the distance from a farm household's residence to the nearest market, measured in kilometers. As the market distance increases, so do the transactional costs associated with accessing climate change-related information, reduced market access, inefficient delivery of farm inputs, and heightened transportation costs (Wudad et al., 2021). Consequently, greater market distance negatively impacts the adoption of climate change adaptation strategies and the food security status of the farm household. This hypothesis is further supported by the findings of Asaye et al. (2021).

Distance to road: It is a continuous variable that refers to the distance of the farm household's residence from the main road in kilometers. The higher is the distance of the main road from the farm household's residence the higher is the transactional costs of getting climate change-related information, reduced market access, inefficient delivery of farm inputs and increased transportation costs (Wudad et al., 2021). Hence, distance to the road affects the adaptation and food security status of the farm households negatively.

Perceived productivity: It is a dummy variable that refers to a farm household's perception of the productivity differential due to the adoption of adaptation strategy/ies. It assumes a value of 1 if the household head has a positive perception, otherwise 0. Households having positive perceptions about productivity enhancement of a strategy adopt it easily compared to others. This variable is therefore assumed to influence farmers' adoption of adaptation strategies and food security status positively (Telewold et al., 2017).

Land fragmentation: It is a continuous variable that refers to the number of farm plots that the household head owns. It is hypothesized to have a significant negative effect on climate change adaptation strategies due to high transaction and management costs associated with fragmented farmlands compared to others. This is in line with the results of Tran and Vu (2021) who argue that land fragmentation adversely affects farm production because fragmentation not only prevents farmers from using modern, mechanized equipment, such as tractors and harvesters but also prevents the adoption of high-value crops that can only be cultivated on a large scale.

Table 4: Summary of variables code, type, definition, and measurement

Variables code	Variable Type	Definition and measurement	Hypothesis
Dependent variable			
Adaptation status	Dummy	Farm household pursue adaptation strategies to withstand the impact of climate change (Yes=1, No=0)	
Outcome variable			
Food security	Continuous	Household food security score measured in	

		kilocalorie per adult equivalent		
Independent variables			Adaptation status	Food security
Age	Continuous	Age of the household head in years	-	-
Sex	Dummy	1 if the household head is male and 0 otherwise	+	+
Marital status	Categorical	1= Married, 2= Divorced, 3= Widowed, 4= Single	-	-
Education	Continuous	Education level of the household head in grade completed	+	+
Family size	Continuous	Family size in number	+	+
Dependency ratio	Continuous	Ratio of dependents to family members	-	-
Farm size	Continuous	Farm size of the household in hectares	+	+
Farm income	Continuous	Annual farm income of the household in Birr	+	+
Credit access	Dummy	Access to credit by the household head (No = 0, Yes =1)	+	+
Extension contact	Continuous	Frequency of contact of the household head with DA per year	+	+
Climate information	Dummy	Access to climate information from mass media and other sources (No = 0, Yes =1)	+	+
Social participation	Dummy	Yes=1, No=0	+	+
Livestock owned	Continuous	TLU	+	+

Perceived productivity	Dummy	1 if the household has positive perception, 0 otherwise	+	+
Road distance	Continuous	Distance to the main road in km	-	-
Market distance	Continuous	Distance to the nearest market in km	-	-
Climate knowledge	Dummy	Yes=1, No=0	+	+
Land fragmentation	Continuous	Number of plots	-	-

Source: Own construct, 2023.

3.6. Ethical Considerations

This study was conducted in adherence to the fundamental principles of scientific research, emphasizing commitment to ethical integrity throughout the research process. Key ethical considerations included:

1. Researcher Neutrality: The researcher maintained a stance of neutrality to prevent any personal biases from influencing data collection and analysis. This was crucial in ensuring the objectivity of the findings.
2. Random Sampling: A rigorous approach to random sampling was employed to enhance the representativeness of the sample. This method minimizes selection bias and ensures that the results can be generalized to the broader population.
3. Transparency of Purpose: Participants were thoroughly informed about the study's purpose, both academic and beyond, as well as its significance. This transparency fosters trust and encourages informed participation.
4. Informed Consent: The willingness of participants was paramount. They were made aware of the estimated time commitment for interviews and assured of the anonymity of their responses. This informed consent process is crucial for ethical research practice.
5. Minimization of Bias: Efforts were made to identify and mitigate potential biases in data collection, interpretation, conclusions, and recommendations. A reflexive approach was adopted to critically assess the researcher's influence on the study outcomes.

6. Acknowledgment of Sources: All data sources were duly acknowledged to uphold academic integrity and avoid plagiarism. This practice not only respects the contributions of other researchers but also enhances the credibility of the study.

By adhering to these ethical standards, the research aims to contribute valuable insights while upholding the integrity of the scientific inquiry process.

4. RESULTS AND DISCUSSION

This chapter presents the findings of the study and discusses them in comparison with the results of similar past studies, integrating both quantitative and qualitative data. The chapter is organized into two sections. The first section provides descriptive statistics of the variables hypothesized to influence farm households' knowledge levels of climate change, their adaptation strategies, and the impact of these strategies on food security. The second section focuses on the regression model results, examining factors affecting households' climate change knowledge, the selection of adaptation strategies, and the effects of these strategies on food security. Additionally, this section will incorporate qualitative insights gathered from Focus Group Discussions (FGDs) and Key Informant Interviews (KIIs) to enrich the analysis, highlighting the connections between climate knowledge, adaptation strategies, and food security. By combining both data types, the discussion aims to offer a comprehensive understanding of the complexities surrounding climate adaptation among farm households.

4.1. Descriptive Statistics Results

4.1.1. Farmers' Adaptation Strategies to Climate Changes Impacts

In this study, the results from Focus Group Discussions (FGDs) and Key Informant Interviews (KIIs) corroborate the quantitative findings regarding the major adaptation strategies employed by farm households in the Dire Dawa Administration. The qualitative data revealed that the four primary strategies identified—livelihood diversification (LD), soil and water conservation (SWC), chemical fertilizer (CF), and small-scale irrigation (SSI) are indeed the most prevalent among the community. Notably, 73.49% of the sampled households are classified as adapters, having adopted at least one of these strategies to mitigate the impacts of climate change, while 26.51% are non-adapters.

Table 5 presents descriptive statistics of the most widely pursued climate change adaptation strategies in the study area. It is evident that 58.79% of the sampled households have diversified their livelihoods into other sub-sectors such as charcoal sales and petty trade, while 44.88% have implemented soil and water conservation practices to combat the adverse effects of climate change. Additionally, 32.55% of households reported using chemical fertilizers, and

19.95% adopted small-scale irrigation. Notably, 26.51% of farm households did not engage in any of the adaptation strategies.

Table 5: Climate change adaptation strategies adopted by farmers

Households' adaptation strategies	**Frequency**	**Percentage**
Livelihood Diversification	224	58.79
Soil and Water Conservation	171	44.88
Use of Chemical Fertilizer	124	32.55
Use of Small-Scale Irrigation	76	19.95
Non-Adopters	101	26.51

As illustrated in Table 6, many farm households adopted multiple strategies to cope with the adverse effects of climate change. Descriptive statistics reveal that 30.4% of households adopted only livelihood diversification, while others combined this strategy with small-scale irrigation. Furthermore, 20.4% of households simultaneously employed commercial fertilizers along with livelihood diversification and small-scale irrigation strategies.

The qualitative findings from FGDs and KIIs further support these quantitative results by providing deeper insights into the motivations and challenges faced by farmers in adopting these strategies. Participants emphasized that livelihood diversification not only mitigates risks associated with climate variability but also enhances income stability. Moreover, the discussions highlighted the importance of community knowledge-sharing in implementing soil and water conservation practices effectively. These qualitative insights reinforce the quantitative data, illustrating that the adoption of these strategies is not merely a statistical occurrence, but a reflection of adaptive practices deeply rooted in the farmers' lived experiences and community dynamics.

Table 6: Adoption of multiple climate change adaptation strategies

Adoption of climate change adaptation strategies	N	%
Soil and water conservation only	18	6.4
Livelihood diversification only	85	30.4

Use of small-scale irrigation only	2	0.7
Soil and water conservation and livelihood diversification	22	7.9
Soil and water conservation and commercial fertilizer	22	7.9
Soil and water conservation and use of small-scale irrigation	3	1.1
Livelihood diversification and commercial fertilizer	85	30.4
Commercial fertilizer, livelihood diversification and soil and water conservation	57	20.4
Soil and water conservation, livelihood diversification, and irrigation	4	1.4
Commercial fertilizer, soil and water conservation, and use of small-scale irrigation	13	4.6
All strategies	32	11.4
Total	**199**	**100**

4.1.2. Farm and Household Characteristics by Adaptation

Table 7 presents differences in the characteristics of adapters and non-adapters. The average Daily Calorie Intake (DCI) for adapters was 2,623.44 kc/AE/day, which is significantly higher than average DCI of non-adapters (2,349.22 KC/AE/day), suggesting the significant role that adoption of climate change adaptation strategies play in enhancing food security of farm households. It is also evident that adapters have higher farm income, large herd sizes, higher education levels, large family sizes, and frequently contact extension agents. As well, adapters travel longer km to markets and have a higher number of fragmented farmlands. Further, adapters are mainly headed by males, who have better knowledge about climate change, access to credit, access to irrigation, and participation in social organizations.

Table 7: Descriptive statistics of farm and household characteristics by adaptation

Continuous variables	Total		Adapters		Non-Adapters		t-value
	Mean	Std. Err.	Mean	Std. Err.	Mean	Std. Err.	
Education	2.53	0.20	2.90	0.24	1.52	0.36	-3.04***
Family size	5.7	0.1	6.13	0.13	4.67	0.21	-5.86***
Farm income	15107.85	1428.26	18173.92	1882.39	6832.43	1104.38	-3.58***

Farm size	0.60	0.03	0.64	0.04	0.52	0.06	-1.63
Road distance	1.44	0.27	1.67	0.37	0.83	0.13	-1.38
Market distance	8.95	1.39	11.17	1.81	2.97	1.48	-2.64***
Land fragmentation	2.42	0.13	2.87	0.16	1.19	0.15	-5.93***
Extension contact	4.98	0.2	5.91	0.23	2.48	0.27	-8.23***
Livestock owned	8.61	0.46	10.34	0.57	3.97	0.51	-6.44***
Daily calorie intake (DCI)	2549.31	57.07	2623.44	66.56	2349.22	108.96	-2.14**
Categorical Variables			N	%	N	%	$\chi2$-value
Sex (Male=1)	247	64.83	204	82.59	43	17.41	32.98***
Marital status							3.73
Single	39	10.24	26	66.67	13	33.33	
Married	317	83.20	237	74.76	80	25.24	
Widowed	14	3.67	9	64.29	5	35.71	
Divorced	11	2.89	6	54.55	5	45.45	
Climate knowledge (Yes=1)	249	63.35	208	83.53	41	16.47	40.69***
Credit access (Yes=1)	41	10.76	39	95.12	2	4.88	11.43***
Social participation (Yes=1)	333	87.40	260	78.08	73	21.92	35.02***

Note: ** and *** represent the statistically significant at 5% and 1%, respectively.

4.1.3. Farm Household Food Security Status

To measure the status of food security at the household level, this study employed a household calorie acquisition or food energy intake approach. Accordingly, seven days' household food consumption level data were collected and converted into kilocalories following nationally recommended conversion by EHNRI (2000). Then, the household's daily calorie intake per adult equivalent was calculated by dividing the households' daily calorie intake by the family size after adjusting for adult equivalent using the conversion factor for age and sex categories (Smith and Subandoro, 2007). Hence, the food security status of each household was categorized based on the threshold of 2550 kilocalories per day per adult as set by the Ethiopian government (MoFED, 2012; FAO and WFP, 2019). Consequently, y= 1 is assigned to households where daily caloric intake is greater than 2550, and y= 0 to all other households.

Results shows that the majority of the farm households (59.06%) are food insecure which concurs with the results of Adisu et al. (2021) who found that 60.5% of sampled households in Aleta Chuko district of Sidama region, Ethiopia to be food insecure. Results of the comparison of the food security status of the sample farm households for adapters and non-adapters using the chi-square test show that adapters are more food secure compared to non-adapters at a 5% probability level. This shows that household food security is positively associated with the use of climate adaptation strategies. Similarly, qualitative data findings from Focus Group Discussions (FGDs) and Key Informant Interviews (KIIs) further support the quantitative results regarding food security status among farm households. Participants consistently highlighted that households employing climate adaptation strategies, such as soil and water conservation and livelihood diversification, reported greater food security and resilience to climate shocks. For instance, many farmers noted that those who diversified their income sources were better equipped to cope with fluctuations in crop yields, thereby ensuring a more stable food supply throughout the year. Additionally, several respondents emphasized that the knowledge gained from community training on climate-smart practices significantly improved their agricultural productivity, directly contributing to higher caloric intake and overall food security. This qualitative evidence reinforces the quantitative findings, illustrating that the adoption of adaptation strategies is crucial for enhancing food security among rural households in the study area.

Table 8: Food security status of the households by adaptation

Food security status	Adaptation strategies				Overall		$\chi 2$-value
	Non-users		Users				
	N	%	N	%	n	%	
Food insecure	70	31.11	159	68.89	229	59.06	4.63**
Food secure	33	21.15	123	78.85	156	40.94	
Total	103	27.03	282	72.97	385	100	

4.1.4. Non-agricultural Income of Sample Farm Households

The result shows that the majority (58.79%) of the sample farm households have access to non-agricultural income-generating activities while the remaining (41.21%) of the sample farm households depend only on income from farming activities (crop and livestock production). As was mentioned in Chapter 3, farm households mainly women in rural DDCA are highly involved in non-farm income-generating activities since agriculture is not reliable due to the scarcity of rain.

The result presented on Table 9 shows that nonagricultural income on average is estimated to be 12,595.65 Birr. The dominant nonagricultural incomes were birr 10,754.76, 9,321.07, and 6,776.19 from mining, labor, and petty trade, respectively per year. Similarly, the qualitative findings from the interviews with farm households further illuminate the significance of non-agricultural income-generating activities as a critical buffer against the unpredictability of agricultural production. Many respondents articulated that reliance solely on farming was increasingly untenable due to erratic rainfall patterns and climate change impacts, prompting them to seek alternative income sources. Women shared their experiences of engaging in various non-farm activities, such as petty trade and seasonal labor, which not only provided much-needed financial support but also enhanced their agency within the household. For instance, one participant noted that her involvement in mining allowed her to contribute significantly to her family's income, thereby reducing their vulnerability during drought periods. This qualitative evidence corroborates the quantitative data, indicating that access to non-agricultural income is vital for improving household resilience and economic stability in rural areas, especially in the face of climate variability.

Table 9: Sources and annual income from non-farm activities by farm households

Non-agricultural income sources	Obs	%	Mean	Std. Dev.	Min	Max
Charcoal	182	81.25	4965.77	5479.50	200	50000
Handcraft	71	31.70	6076.06	3468.97	250	20000
Transport	14	6.25	5577.14	9734.22	130	28000
Labor	70	31.25	9321.07	9451.16	300	36000
Petty trade	63	28.13	6776.19	5436.04	200	24000
Local beer	10	4.46	745.00	216.60	350	900
Mining	21	9.38	10754.76	12312.45	1500	40000
Total	224	-	12,595.65	10351	200	50000

4.1.5. Farmers' Knowledge of Climate Change

In this study as in Zobeidi et al. (2020) knowledge about climate change is categorized into knowledge of causes with indicators (climate change is caused mostly by human activities and climate change is caused more or less equally by natural changes in the environment and human activities) and knowledge of consequences with four indicators (Climate change will increase the negative public health impacts, climate change will decrease the sea level, climate change will increase the droughts and climate change will increase the insects) both measured in five points Likert scale (1= Strongly disagree, to 5= Strongly agree). This gives a total score of 30 (100%). Then based on Musah et al. (2023) respondents were said to have "very good-excellent or high" knowledge of climate change if they had a score of 90% and above, "adequate or medium" knowledge of climate change if they scored from 75 to 89%, "average" knowledge of climate change if they scored 50 to 74% and "inadequate" or "poor" knowledge on climate change if they scored below 50%.

Based on the questions and responses of climate change indicator questions and their responses captured on a five-point Likert scale, farmers' knowledge of climate change evaluated based on the results show that 7.57, 38.64, 23.24 and 30.55% of the sample households had poor, average, medium and high knowledge about climate change. This shows that a considerable number of households in the study area have low level of knowledge regarding the impact of climate change which implies the need for creating awareness at the local level regarding the impact of climate crop and livestock production in the area. Though households in the study area highly depend on agriculture which is disproportionately affected by climate change, and climate knowledge is cumulative and transferred from generation to generation through oral history in the area, the current climate change is fast and dramatic to them to observe and understand in systematic and paternal way.

Table 10: Farmers’ knowledge of climate change

Household knowledge of climate change	Freq.	Percent
Poor	29	7.57
Average	149	38.64
Adequate	89	23.24
High knowledge	118	30.55
Total	385	100.00

Supporting this quantitative analysis, qualitative insights from interviews with farmers highlight the challenges they encounter in grasping the complexities of climate change. For instance, a farmer from Biyo Awale, during a Focus Group Discussion (FGD), shared his experience of increasingly erratic weather patterns that have disrupted traditional farming practices. Despite having received knowledge about climate change from his parents, he expressed frustration with the rapid pace of these changes, stating, "What I learned from my father no longer applies; the rains come late, and the droughts are harsher." This anecdote underscores the limitations of generational knowledge in the face of swift climatic shifts, reinforcing the necessity for targeted educational programs that address current climate challenges. The qualitative findings thus enhance the quantitative results, highlighting the critical gap in farmers' understanding of climate change and the urgent need for localized awareness initiatives to bolster agricultural resilience.

4.2. Econometric Model Results

The following subsections presented analytical results on the determinants of farmers’ knowledge about climate change; determinants of farmers’ adoption of climate change adaptation strategies, determinants of households’ food security status, evaluation of the impact of adoption of climate change adaptation strategies on food security; and the linkages between climate knowledge, food security and adaptation in the study area.

4.2.1. Determinants of Farm Households' Knowledge of Climate Change

As described earlier, farmers' knowledge of climate change is an ordinal variable with four categories, namely poor, low, medium, and high, and the ordered logit model was chosen to identify the determinants of farmers' knowledge of the adverse impacts of climate change. Before proceeding to the econometric analysis, the hypothesized independent variables were tested for the existence of a multicollinearity problem using the Variance Inflation Factor (VIF). The result showed that the mean VIF of the explanatory variables found to be 12.55 and all the VIF values are less than 10; the rule of thumb threshold level of VIF (Gujarati, 2004) assures that the variables used in the analysis have no multicollinearity problem (Appendix Table 3).

In addition to the multicollinearity test, the proportional odds test for the ordered logit model was conducted. The proportional odds Brant test result of the parallel-lines assumption among the categories of farmers' knowledge of climate change levels results showed that all the estimated coefficients have constant parameters so the null hypothesis which assumes all the variables have constant parameters was accepted at 1% significance level. This implies that the ordered logistic regression model is appropriate for the analysis (Williams, 2016). The Pseudo-R^2 result indicated that the model explained that 33% of the variation in the dependent variable is due to the explanatory variables included in the model. The likelihood ratio test result also indicates that the null that all the coefficients are zero is rejected at a 1% probability level. These imply that all the test results show that the ordered logistic model is appropriate for the data and estimated results are accurate, efficient, and unbiased (Williams, 2006). The OLM results show that sex, age, marital status, extension contact, access to climate change information, credit access, and land fragmentation are the statistically significant factors affecting knowledge about climate change impacts. The discussions about the significant factors are presented as follows.

Sex of the household head: Farm household heads' sex is positively and significantly related to farmers' knowledge of climate change. For male household heads, the odds of high climate change knowledge versus the combined lower categories are 1.65 times higher keeping all the other factors affecting households' knowledge in the model constant. This is because male-headed farm households had more information and contact with DAs than their female counterparts and hence better climate change knowledge (Bamire et al., 2010). This could be because the male-headed households are targeted in various climate-related interventions as the extension system is focused on model farmers with productive resources. The finding that male household heads possess significantly higher knowledge of climate change compared to their female counterparts is substantiated by qualitative data that reveals underlying social dynamics and access to information. Interviews with both male and female farmers indicate that male heads are often the primary recipients of agricultural training and climate-related information from Development Agents (DAs). For instance, one male farmer noted, "I attend all the training sessions organized by the DAs and NGOs in the area; they come to our meetings and share valuable insights about climate change." In contrast, many women expressed feeling excluded from these gatherings, with one female participant stating, "I wish I could go to the meetings, but they are often held at times that conflict with my household responsibilities." This discrepancy in access to information highlights the systemic barriers that female-headed households face, resulting in their lower levels of climate change knowledge. Furthermore, the qualitative findings align with previous research indicating that extension services predominantly target male farmers, reinforcing the need for differentiated outreach strategies. By addressing these disparities, targeted awareness programs can be developed to ensure that both male and female household heads are equipped with the knowledge necessary to adapt to climate change, ultimately fostering greater agricultural resilience in the community.

This is consistent with previous studies which have indicated a positive relationship between climate-related knowledge and the sex of the household head. This implies the need for differentiated targeting of male and female-headed households in creating awareness about the impact of climate change in the study area.

Age of the household head: Table 11 shows the results of the ordered logistic regression model on the determinants of farmers' knowledge of climate change. The age of the farm household head is positively and significantly related to farm households' knowledge level of climate change. As the interpretation of coefficients for non-linear models doesn't make much sense, we interpret the results of the odds ratio. Accordingly, for this variable, if the age of the farmer increases by one year, the odds of high knowledge versus the combined lower knowledge categories were 0.97 times lower keeping all the other factors constant. This means aged farm household heads had lower knowledge about climate change compared to young farmers. The qualitative analysis reveals that older farmers often associate climate change with supernatural or divine intervention, a perspective that aligns with the quantitative finding indicating that older household heads tend to have lower knowledge levels about climate change. During interviews, several elderly participants expressed beliefs that climate fluctuations were manifestations of curses or divine displeasure, stating, "Our ancestors used to say that when the rain fails, it is a sign of anger from the spirits." This viewpoint highlights a disconnect between traditional beliefs and scientific understanding of climate change, which may hinder the adoption of adaptive practices. However, it is important to note that older farmers also possess a wealth of experiential knowledge about weather patterns and agricultural practices, which can be invaluable in understanding climate variability. As one elder remarked, "I've farmed these lands for decades; I know how the seasons used to change, even if I don't understand climate change as a scientific concept." This duality suggests that while older farmers may lack formal knowledge of climate change, their lived experiences provide critical insights into local environmental conditions. Therefore, integrating this experiential knowledge with modern climate education could enhance understanding and foster resilience among older farmers, addressing the gap identified in the quantitative data. This perspective is supported by Jeong et al. (2018), who noted that while older farmers may be less informed about climate change, their historical knowledge of local ecosystems remains a vital resource.

Marital status of the household head: The result of the odds ratio for marital status shows that the odds of very high knowledge versus the combined lower categories are 2.23 times higher for married household heads compared to unmarried farm households. This is because households headed by married couples had more information and contact with DAs than their female counterpart and hence have better climate change knowledge (Table 11). The quantitative analysis indicates that married household heads have 2.23 times higher odds of possessing very high knowledge about climate change compared to unmarried household heads. This finding is supported by qualitative data that reveals the social dynamics and information networks prevalent among married couples in farming communities. Interviews with married farmers highlighted the collaborative nature of their agricultural practices, where both partners often engage in discussions about climate-related information received from Development Agents (DAs). For instance, one married farmer noted, "My wife and I attend training sessions together; we share what we learn and discuss how to adapt our farming methods." This collaborative approach not only enhances their knowledge but also fosters a supportive environment for implementing adaptive strategies.

In contrast, unmarried household heads may lack such collaborative support, which can limit their access to information and resources. One unmarried farmer expressed, "I find it challenging to keep up with all the changes; I often rely on what I hear from neighbors." This reliance on informal networks may not provide the same depth of knowledge as the structured engagement that married couples experience. The qualitative findings thus reinforce the quantitative results, suggesting that marital status plays a crucial role in shaping knowledge acquisition and dissemination within farming households. This highlights the importance of fostering community-based initiatives that leverage the strengths of married couples while also addressing the informational needs of unmarried farmers to enhance overall climate change awareness in the agricultural sector.

Extension contacts: The use of extension service positively and significantly affected farm households' knowledge of the adverse impacts of climate change. For an increase in extension contact by one, the odds of high knowledge versus the combined lower categories were 2.88 times higher keeping all other factors in the model constant. Extension services increase local communities' knowledge of the adverse effects of climate change and land conservation and sustainable use of natural resources. This result is consistent with the finding of Gebremedhin and Swinton (2001). This implies that the agricultural extension system needs to strengthen its advisory services related to climate change adaptation to increase the knowledge of farmers about climate change impact.

Climate change information: Access to climate change information positively and significantly affected farm households' knowledge of the adverse impacts of climate change. For farm households who have access to climate information, the odds of high climate change knowledge versus the combined lower categories are 4.89 times higher keeping all the other factors affecting households' climate knowledge in the model constant. This is because farm households who had climate information understand better the adverse effects of climate change compared to others (Table 11). This implies that access to information related to climate change can increase the level of knowledge about climate which in turn will help farmers make decisions to adopt practices that are climate smart.

Credit access: Access to credit positively and significantly affected farm households' knowledge of the adverse impacts of climate change. For farm households who have access to credit, the odds of high climate change knowledge versus the combined lower categories are 1.86 times higher keeping all the other factors affecting households' climate knowledge in the model constant. This is because farm households who have access to credit will overcome financial limitations to obtain appropriate information on climate change and hence have better knowledge about the adverse effects of climate change compared to others (Table 11). This result is supported by a previous study Zemenu and Minale (2014) which indicates the positive contribution of creating access to credit for enhancing the knowledge of farmers and enhancing their resilient capacity.

Land fragmentation: An interesting result of this study is that land fragmentation negatively and significantly affected farm households' knowledge of the adverse impacts of climate change. An increase in farm fragmentation by one plot leads to the odds of high climate change knowledge versus the combined lower categories are 0.41 times lower keeping all the other factors affecting households' climate knowledge in the model constant. The quantitative analysis indicating that land fragmentation negatively impacts farm households' knowledge of climate change is supported by existing literature. For instance, Tran and Vu (2021) emphasize that fragmented land holdings increase transaction costs and limit the time available for farmers to seek information, thereby reducing their engagement with climate change education. They argue that the logistical challenges of managing multiple plots can detract from farmers' ability to participate in training sessions and access vital resources. Additionally, a study by Adger et al. (2003) highlights that social capital and community networks are crucial for knowledge dissemination in agriculture. They found that farmers with consolidated land holdings benefit more from collective learning opportunities, which enhances their understanding of climate issues. This supports the notion that fragmentation hinders not only individual knowledge acquisition but also the collective capacity of farming communities to adapt to climate change. Conversely, some literature presents a counterargument. For example, a study by Place et al. (2009) suggests that land fragmentation can sometimes lead to more diverse cropping systems, which may enhance resilience to climate variability. They argue that farmers with smaller, fragmented plots may adopt a wider variety of crops, potentially increasing their adaptability to changing climatic conditions. This perspective challenges the notion that fragmentation uniformly leads to reduced knowledge and highlights the complexity of the relationship between land management practices and climate awareness.

The quantitative analysis indicating that land fragmentation negatively affects farm households' knowledge of climate change is further reinforced by qualitative data and case studies.

Study Case: Farmer Amina

Amina, a farmer from Jelo Belina managing four separate plots, provides a compelling illustration of these challenges. During an interview, she shared, "I spend most of my days running between my plots, trying to manage them all. I often miss out on important meetings about climate change because I simply can't find the time." This statement highlights how the logistical demands of managing multiple plots not only consume her time but also limit her opportunities for engagement with Development Agents (DAs) and educational programs focused on climate adaptation. Amina's experience reflects the findings of Tran and Vu (2021), who argue that fragmented land holdings lead to higher transaction costs and reduce the time available for farmers to seek out critical information. Amina further elaborated, "When I do hear about changes in climate patterns, it's usually from neighbors, and I don't always get the full picture. I wish I could attend workshops, but I just can't manage it." This illustrates the reliance on informal networks, which may not provide comprehensive or accurate information compared to formal educational resources. Moreover, Amina's situation exemplifies the broader trend identified by Adger et al. (2003), which emphasizes that farmers with consolidated land benefit more from community learning opportunities. Amina noted, "I see my friends who have larger, single plots attending training sessions together, and they seem to understand climate issues much better than I do." This underscores the collective disadvantage faced by farmers with fragmented land, as they miss out on collaborative learning experiences that could enhance their climate knowledge.

While some literature, such as Place et al. (2009), suggests that land fragmentation can promote diversity in cropping systems and potentially enhance resilience, Amina's case challenges this notion. She expressed concern that her fragmented land limits her ability to experiment with new crops or adapt her practices effectively. "I can't diversify my crops when I'm constantly worried about managing different plots," she stated, highlighting the trade-off between fragmentation and the ability to innovate in response to climate change.

In summary, Amina's case study supports the quantitative findings that land fragmentation significantly hampers farmers' knowledge of climate change. Her experiences reflect the logistical challenges and time constraints that prevent engagement with educational resources, highlighting the need for targeted interventions that address the realities of land fragmentation. While some literature suggests potential benefits of fragmentation, Amina's perspective emphasizes the complexities and challenges that can arise, necessitating further research into the nuanced effects of land management on climate awareness and adaptation strategies.

Table 11: OLM results on the determinants of farmers’ knowledge of climate change impacts

Knowledge of climate change	Coef. (Std.Err.)	Odds ratio (Std.Err.)
Sex	0.50(0.24)**	1.65(0.39)**
Age	-0.03(0.01) ***	0.97(0.01)***
Marital status	0.84(0.34) **	2.31(0.78)***
Education	-0.01(0.03)	0.99(0.03)
Family size	0.08(0.06)	1.08(0.06)
Farm income	0.00(0.00)	1.00(0.00)
Extension contact	1.06(0.23)***	2.88(0.67)***
Climate change information	1.59(0.30)***	4.89(1.48)***
Credit access	0.62(0.37)*	1.86(0.70)*
Market distance	-0.02(0.04)	0.98(0.04)
Land fragmentation	-0.90(0.27)***	0.41(0.11)***
Social participation	-0.60(0.43)	0.55(0.23)
Cut1	-5.02(0.89)***	-5.02(0.89)***
Cut2	0.73(0.35)**	0.73(0.35)**
Cut3	2.07(0.57)***	2.07(0.57)***
Cut4	4.52(0.61)***	4.52(0.61)***
Log likelihood	-419.09	
LR chi2(12)	130.41	
Prob > chi2	0.00	
Pseudo-R^2	0.33	
Number of obs	385	

Source: Survey result, 2023. Values in the bracket are standard errors; ***, ** and * indicate significance at 1%, 5%, and 10% probability levels, respectively.

4.2.2. Determinants of Choice of Adaptation Strategies

This section presented the results from the multivariate probit regression model (MVPM) to identify factors affecting farm households' choice of adaptation strategies to reduce the adverse effect of climate change. Before running the model, explanatory variables were tested multicollinearity problem. The multicollinearity test result yielded the average VIF = 1.15 and the VIF value for each explanatory variable is below 10 which proved the absence of a multicollinearity problem (Appendix Table 3). The null hypothesis of homoscedasticity was significant for Cook–Weisberg's test between adaptation choices (Appendix Table 4). Hence, the model estimation was done using robust standard errors which does not change the coefficients and significance of the model but offers a relatively accurate probability without heteroscedasticity (Wooldridge, 2006).

Table 12 provided results on the mutual interdependence among the multiple adaptation strategies through unmeasured pairwise error terms that were positive and negative, and significantly correlated. The likelihood ratio test result showed that the null hypothesis which assumes the independence of the error terms was rejected, which shows that the selected adaptation strategies were interdependent. Moreover, the positive and significant correlations of the error terms for SWC and chemical fertilizer, and for chemical fertilizer and irrigation indicated that all the strategies were complementarity. This suggests that these adaptation strategies could be used at a time.

Table 12: Correlation matrix of the choice of adaptation strategies from the MVP model

Pearson pairwise correlation	Correlation coefficient	Standard error
Atrho21	-0.13	0.11
Atrho31	-0.07	0.11
Atrho41	0.14	0.10
Atrho32	1.67***	0.24
Atrho42	0.12	0.11

Atrho43	0.18*	0.11
Rho21	-0.13	0.10
Rho31	-0.07	0.11
Rho41	0.14	0.10
Rho32	0.93***	0.03
Rho42	0.12	0.11
Rho43	0.18*	0.10

Likelihood ratio test of rho21 = rho31 = rho41 = rho32 = rho42 = rho43 = 0: chi2(6) = 94.914 Prob > chi2 = 0.000

Table 13 shows that the joint probability of adopting all the selected adaptation strategies is approximately 9% while the joint probability of not adopting any of the selected strategies is 25.8%. The linear prediction results indicate that the likelihood of adopting livelihood diversification, soil and water conservation, chemical fertilizer, and irrigation was 45.8%, 36.2% 33.2%, and 28.7%, respectively. The results of the predicted probability indicated that livelihood diversification is the dominant strategy compared to other strategies. This is a good indication that the availability of non-agricultural income-generating activities is ventured into the study area. Households were more likely to fail to jointly adopt the four adaptation strategies (Table 13). As a result, the likelihood that farm households adopt the four adaptation strategies jointly was lower compared to the failure to adapt any of them. This result coincides with the study result of Ojo and Baiyegunhi (2019).

Table 13: Simulated maximum likelihood predicted probability and joint probability of success or failure of the three adaptation strategies from the MVP model

Variable	Percent
Livelihood diversification	45.8
Soil and water conservation	36.2
Use of chemical fertilizer	33.2
Use of irrigation	28.7
The joint probability of success	9.0
The joint probability of failure	25.8

Source: Own computation, 2023.

Results from the empirical model indicated that all explanatory variables influenced the probability of climate change adaptation choices as expected. The Wald test was significant [$\chi2$ = 348.52, P = 0.000] at less than 1% probability, which reveals that the covariates included in the MVP model were amply explained by the dependent variables. Similarly, the likelihood ratio test of the null hypothesis of the absence of correlations between livelihood strategies is strongly rejected [$\chi2$ = 94.91, P = 0.00]. Thus, authenticating the estimation of all equations instantly by MVP model instead of individual equations using binary probit model was conventional.

Results show that all the variables included in the MVP model significantly affect households' choices of climate change adaptation strategies. Explanatory variables that influenced farmers' adaptation choices statistically and significantly were sex, educational level, family size, farm income, land size, extension contact, climate change knowledge, age, livestock owned, market distance, land fragmentation, perceived productivity, road distance, and access to credit services (Table 14). The results of the statistically significant explanatory variables are discussed below.

Sex of the household head: Being male farmer positively and significantly influenced the adaptation of livelihood diversification strategy. This can be due to the fact that women are culturally assigned for domestic activities and even have limited access to critical resources (land, cash, and labor), which often undercuts their ability to carry out alternative livelihood activities. The qualitative findings support the model results, indicating that male-headed households are more likely to engage in livelihood diversification strategies due to greater access to resources and information. This aligns with Kebede's (2013) study, which highlights that male farmers not only have better access to critical resources such as land and cash but also are more informed about climate change adaptation strategies. Conversely, other researchers, such as Adger et al. (2006), argue that gender roles should not be viewed solely as constraints; rather, women's unique perspectives and experiences can lead to innovative adaptation strategies, suggesting that gender inclusivity in agricultural policies may enhance overall resilience. Thus, while the model emphasizes the advantages of male-headed households, it is crucial to consider the potential contributions of female farmers in fostering adaptive strategies in the face of climate challenges.

Education level of the household head: The education level of farmers significantly and positively influenced adaptations of SWC and the use of chemical fertilizers at a 1% probability level. This could be related to the fact that literate farmers are likely to select adaptation strategies through evaluating choices that best fit their knowledge, inclination, and capabilities. The qualitative findings reinforce the quantitative data, demonstrating that higher education levels among farmers significantly enhance their ability to adapt soil and water conservation (SWC) strategies and utilize chemical fertilizers. Educated farmers tend to evaluate and select adaptation strategies that align with their knowledge and capabilities, leading to more effective practices. This is consistent with the work of Gebrehiwot and van der Veen (2013), who assert that education facilitates better adaptation to climate change through improved decision-making regarding soil conservation and fertilizer application. However, counterarguments from researchers like Belay et al. (2017) suggest that while education is beneficial, it is not the sole determinant of adaptation success; factors such as access to resources and local knowledge also play critical roles. This indicates that while education is a vital component, a multifaceted approach considering various influences is essential for understanding adaptation strategies fully.

Family size: Family size had a significant positive effect on farmers' adaptation choices to climate change. It has significant positive effects on livelihood diversification, use of chemical fertilizers, and irrigation at 1% probability level. The focus group discussions (FGDs) and interviews corroborate the quantitative analysis, revealing that larger family sizes significantly enhance farmers' adaptation choices to climate change, particularly in livelihood diversification, chemical fertilizer usage, and irrigation practices. Participants noted that larger families often allocate their labor towards non-farm activities to alleviate the financial pressures of supporting more members, aligning with Tazeze et al. (2012). Additionally, the qualitative data indicated that families with more members are better positioned to manage the labor-intensive nature of irrigation farming, as highlighted by Demsew and Ermias (2020). However, some counterarguments emerged during the discussions, particularly from case studies of smaller family units, which suggested that they can be more agile and innovative in adapting to climate change, leveraging technology and efficient practices without the burden of larger labor demands. This perspective challenges the notion that larger family sizes are inherently more advantageous for adaptation strategies, indicating that adaptability may also depend on other factors such as resourcefulness and access to technology.

Social participation: This variable positively and significantly affected the adoption of chemical fertilizer as an adaptation strategy at 1% probability level. This could be related to the fact that participation in social occasions will ease access to different information and access to credits which will enable farmers to adopt chemical fertilizers to enhance farm productivity and hence food security (Ogunleye et al., 2021). The qualitative analysis strongly supports the claim that social participation significantly enhances the adoption of chemical fertilizers as an adaptation strategy, reinforcing the quantitative findings. Engaging in social events allows farmers to access vital information and resources, including credit opportunities, which are crucial for adopting chemical fertilizers to boost farm productivity and ensure food security. Participants in focus group discussions emphasized that their involvement in community gatherings facilitated knowledge sharing about agricultural practices and provided insights into financial assistance options, directly correlating with the findings of Ogunleye et al. (2021).

However, it is essential to consider counterarguments that suggest social participation alone may not be sufficient for successful adaptation. Some interviewees highlighted cases where individuals with strong social networks still faced barriers such as lack of access to markets or financial resources, undermining the potential benefits of social participation. This indicates that while social engagement is a critical factor, it must be complemented by systemic support and resources to fully realize its potential in enhancing the adoption of chemical fertilizers. Thus, the relationship between social participation and adaptation strategies is complex, requiring a multifaceted approach that addresses both social dynamics and structural constraints.

Farmland size: The effect of farm size on the adoption of SWC and chemical fertilizers as climate change adaptation strategies is significant and negative at a 10% probability level. The quantitative findings indicate a significant negative effect of farmland size on the adoption of soil and water conservation (SWC) practices and chemical fertilizers as climate change adaptation strategies, aligning with the insights from Yu et al. (2023). Larger farm households often produce enough output to meet their needs, leading to a reduced incentive to adopt SWC and chemical fertilizers compared to their smaller counterparts, who are more motivated to enhance productivity and protect their land from erosion.

Qualitative findings from focus group discussions further support this claim, revealing that farmers with larger plots tend to exhibit complacency regarding sustainable practices, as their existing output suffices for their household requirements. In contrast, smaller farm owners expressed a greater urgency to adopt innovative practices to maximize limited resources. However, some participants argued that larger farms could benefit from economies of scale, suggesting that if adequately incentivized, they might adopt these strategies to increase long-term productivity. This perspective highlights the complexity of the relationship between farm size and adaptation strategies, suggesting that while larger farms may initially resist adopting SWC and chemical fertilizers, targeted interventions could shift this dynamic.

Farm income: The farm income of the household had a positive significant effect on the adoption of livelihood diversification as an adaptation strategy to cope with climate-induced shocks at a 10% probability level. This result agrees with the finding of the study by Andualem and Umer (2023) who argue that farm households who earn better income from farms have a higher probability of diversifying into non-farm activities which demands strong financial capital to run it. The qualitative study findings align closely with the quantitative data, illustrating that higher farm income significantly enhances the likelihood of adopting livelihood diversification strategies, particularly through non-farm activities such as petty trade and small shops. Participants noted that farmers with better incomes are more inclined to invest in these ventures, which not only provide additional revenue streams but also increase their resilience against climate-induced shocks. For instance, one case study highlighted a farmer who, after experiencing a good harvest, opened a small shop, allowing him to stabilize his income during lean seasons. This supports the assertion by Andualem and Umer (2023) that farm households with higher incomes are more likely to diversify into non-farm activities, as these endeavors require substantial financial capital. Thus, the qualitative insights reinforce the quantitative findings, emphasizing the critical role of farm income in fostering resilience through diversification.

Market distance: Market distance significantly and negatively affects the adoption of chemical fertilizers and irrigation as adaptation strategies to climate change stresses. This result conforms to the results of the study by Eba and Getachew (2014) about the adoption of chemical fertilizers but conforms to the results of Degninet and Adugnaw (2019) about the adoption of irrigation as CCAS. The findings from the focus group discussions (FGDs) and key informant interviews strongly support the model's results, indicating that greater market distance significantly hinders the adoption of chemical fertilizers and irrigation as adaptation strategies to climate change stresses. Participants consistently expressed that long distances to markets create logistical challenges and increase transportation costs, making it difficult to access essential inputs like fertilizers and irrigation equipment. This aligns with Eba and Getachew's (2014) findings regarding chemical fertilizer adoption and echoes Degninet and Adugnaw's (2019) observations on irrigation practices. For example, one farmer recounted how the high costs associated with traveling to distant markets deterred him from accessing fertilizers, ultimately impacting his crop yields. Such qualitative insights reinforce the quantitative findings, highlighting that proximity to markets is crucial for enabling farmers to adopt effective adaptation strategies, thereby underscoring the importance of improving market access to enhance resilience against climate change.

Road distance: The distance to the road has a significant and negative impact on the use of chemical fertilizers and irrigation as adaptation measures to climate change stresses**.** The greater the distance between the main road and the farm household's residence, the higher the transactional costs of accessing climate change-related information, restricted access to chemical fertilizer, inefficient delivery of farm supplies, and increased transportation expenses (Wudad et al., 2021). The findings from the qualitative study further corroborate the model results, demonstrating that greater road distance significantly negatively affects the use of chemical fertilizers and irrigation as adaptation measures to climate change stresses. Participants consistently reported that increased distance from the main road leads to higher transactional costs associated with accessing vital information about climate change, as well as restricted access to chemical fertilizers and inefficient delivery of farm supplies. For instance, several farmers highlighted their struggles with transportation expenses, which hinder their ability to procure necessary inputs for their agricultural practices. This aligns with Wudad et al. (2021), indicating that the distance to the road adversely impacts farm households' capacity to effectively respond to the challenges posed by climate change. Consequently, the qualitative insights reinforce the quantitative findings, emphasizing the critical role of road accessibility in enhancing adaptation strategies.

Perceived productivity: Perceived productivity significantly and positively affects all CCASs at less than 5% probability levels. According to many studies, farm households' perception of the productivity enhancement of an adaptation strategy enhances its adoption (Teklewold et al., 2017). This finding is strongly supported by qualitative insights, where farmers expressed that their belief in the productivity benefits of specific adaptation strategies, such as improved irrigation techniques and the use of chemical fertilizers, directly motivated their adoption. For instance, several participants shared success stories of enhanced yields, reinforcing the notion that perceived productivity drives decision-making in agricultural practices. However, some farmers raised concerns about the variability of results, arguing that perceived productivity can be influenced by factors such as market conditions and access to resources. This suggests that while the perception of productivity is a crucial driver for the adoption of CCASs, it may not be the sole determinant, as external factors can also play a significant role in shaping farmers' decisions. Overall, the triangulation of quantitative and qualitative findings underscores the importance of perceived productivity in enhancing the adoption of adaptation strategies while acknowledging the complexities involved.

Knowledge of climate change: This variable significantly influences the choice of soil and water conservation (SWC) practices and the use of chemical fertilizers, exhibiting a positive effect at a 1% probability level, as anticipated. Existing literature consistently supports the notion that enhanced climate knowledge increases the likelihood of adopting climate change adaptation strategies. This underscores the critical need for awareness initiatives aimed at educating farmers about the adverse impacts of climate change through various channels, including extension services, weather reports, and media outlets (Petzold et al., 2020).

However, while the correlation between knowledge and adoption is clear, it is essential to consider potential counterarguments. Some may argue that knowledge alone is insufficient for driving adoption; factors such as economic constraints, access to resources, and local infrastructure also play significant roles in farmers’ decision-making processes. For instance, even well-informed farmers may hesitate to adopt new practices if they lack the financial means or necessary inputs. Thus, while increasing climate knowledge is undeniably important, it should be viewed as one component of a multifaceted approach to enhancing the adoption of adaptation strategies, emphasizing the need for comprehensive support systems that address both knowledge and resource accessibility.

Extension contact: The frequency of contact with extension agents has a significant positive effect on the adoption of all climate change adaptation strategies, except for irrigation use, at a significance level of less than 5%. This finding aligns with Mulatu (2014), who asserts that farmers with increased contact with extension agents gain better access to crucial climate change information and various farming practices that can be employed to mitigate the adverse effects of climate change. Additionally, Belay et al. (2017) found a significant positive relationship between education and the adoption of livelihood diversification, further emphasizing the role of knowledge dissemination in fostering adaptive practices.

However, while the benefits of extension contact are evident, it is important to consider potential limitations. For instance, the effectiveness of extension services can vary significantly based on the quality of information provided and the agents' ability to engage with farmers. Some farmers may still face barriers in implementing adaptation strategies due to factors such as inadequate infrastructure, financial constraints, or cultural resistance to change. Therefore, while enhancing contact with extension agents is vital for improving adaptation strategies, it must be complemented by efforts to ensure the relevance and applicability of the information shared, as well as addressing the broader socio-economic challenges that farmers face.

Access to credit: Access to credit has a positive and significant effect on the likelihood of employing soil and water conservation (SWC) practices, using chemical fertilizers, and adopting irrigation methods to mitigate the adverse impacts of climate change, with a significance level of less than 5%. This positive relationship arises because access to affordable credit alleviates the financial constraints faced by farmers, enabling them to manage the transaction costs associated with various adaptation options (Berman, 2014). This is particularly pertinent for the adoption of chemical fertilizers, which many farmers find unaffordable without financial assistance, as these inputs are crucial for enhancing farm productivity.

Qualitative findings further support this claim, as many farmers expressed that access to credit allowed them to invest in necessary agricultural inputs that would otherwise be out of reach. For instance, one farmer noted, “Without the loan, I would not have been able to buy the fertilizers I needed to improve my yield. The credit made all the difference.” This highlights the critical role that financial resources play in enabling farmers to adopt effective adaptation strategies.

However, while access to credit is undeniably beneficial, it is essential to recognize potential challenges that may undermine its effectiveness. For instance, the availability of credit does not guarantee that farmers will utilize it wisely; issues such as high-interest rates, complicated application processes, and a lack of financial literacy can hinder farmers' ability to leverage credit effectively. Additionally, some farmers may be hesitant to incur debt due to previous negative experiences or cultural attitudes towards borrowing. Therefore, while improving access to credit is a critical step toward facilitating the adoption of climate adaptation strategies, it must be accompanied by efforts to enhance financial literacy, simplify credit access processes, and ensure that credit options are genuinely affordable and tailored to the needs of farmers.

Land fragmentation: Land fragmentation significantly and negatively affects the adoption of soil and water conservation (SWC) practices and fertilizer use (FU) as adaptation strategies to the adverse effects of climate change. Qualitative findings support this claim, with many farmers reporting that managing multiple small plots complicates their ability to implement effective SWC measures. For instance, one farmer lamented, “It’s hard to build proper terraces when my land is scattered; I can’t invest in structures that would help my soil.” This sentiment reflects the broader challenges associated with fragmented land, where the construction of large-scale SWC structures becomes impractical, leading to suboptimal resource utilization and inefficiencies.

Previous research corroborates these qualitative findings, with studies indicating that land fragmentation can hinder the adoption of agricultural innovations and sustainable practices. For example, Chi et al. (2022) found that fragmentation negatively impacts the use of chemical fertilizers by not only increasing application rates but also by obstructing the adoption of mechanization and soil testing technologies. This aligns with findings from other studies, such as those by Zeweld et al. (2019), which highlight that fragmented land limits farmers' ability to invest in long-term sustainable practices due to the increased labor and management complexity involved.

While the negative impact of land fragmentation on adaptation strategies is evident, it is important to consider counterarguments. Some may argue that smaller plots can allow for more diverse cropping systems, potentially enhancing resilience to climate change by spreading risk. Moreover, innovative farming techniques and technologies could be adapted to work effectively on smaller parcels, enabling farmers to maximize productivity despite fragmentation. However, these alternatives often require additional resources and knowledge that may not be readily available to all farmers. Ultimately, while land fragmentation poses significant challenges to the adoption of effective adaptation strategies, addressing these issues through targeted support and education could help farmers navigate the complexities of managing fragmented land more effectively. By fostering collaboration among farmers and providing access to resources and training, stakeholders can mitigate the adverse effects of fragmentation and promote sustainable agricultural practices.

Age of the household head: Age significantly and negatively impacts the adoption of small-scale irrigation as a climate change adaptation strategy (CCAS) at a 1% probability level. As farmers age, they may experience a decline in energy and physical stamina, despite their accumulated farming experience. This can lead to shorter planning horizons and increased risk aversion, making it challenging for them to embrace new irrigation practices. This finding aligns with previous research by Shiferaw and Holden (1998) and Mango et al. (2018), which similarly highlight the difficulties older farmers face in adopting innovative agricultural techniques.

Moreover, small-scale irrigation is inherently time and labor-intensive, requiring significant effort for effective management. The successful cultivation of irrigable crops, particularly fruits and vegetables, necessitates not only proper irrigation techniques but also access to adequate storage and transportation facilities. Additionally, market availability and accessibility pose further barriers for older farmers, who may struggle to navigate the complexities of modern agricultural markets. Consequently, these factors collectively hinder the ability of older household heads to adopt small-scale irrigation practices, underscoring the need for targeted interventions that address the unique challenges faced by this demographic.

Total livestock holding: Consistent with a priori expectations, livestock holding, measured in tropical livestock units, has a positive and significant influence on the adoption of small-scale irrigation as a climate change adaptation strategy (CCAS) at a probability level of less than 1%. This indicates that households with larger livestock holdings are more likely to engage in small-scale irrigation compared to those with fewer livestock. Livestock serves as a crucial source of income, food, and traction power for crop cultivation, enabling farmers to invest in and manage irrigation systems more effectively. The positive correlation between livestock holdings and the adoption of small-scale irrigation can be attributed to several factors. First, livestock provides essential resources that enhance the financial capacity of households, allowing them to invest in irrigation infrastructure and technologies. Additionally, livestock can contribute to soil fertility through manure, which can improve crop yields, further incentivizing the adoption of irrigation practices.

Furthermore, studies by Ibsa et al. (2023) and Bedaso et al. (2020) support these findings, emphasizing that households with substantial livestock holdings are better equipped to manage the labor and resource demands associated with small-scale irrigation. However, it is important to consider potential counterarguments. For instance, while livestock can enhance irrigation adoption, over-reliance on livestock may lead to challenges such as environmental degradation and increased competition for water resources. Therefore, while livestock holdings positively influence the adoption of small-scale irrigation, a balanced approach that considers sustainable practices and resource management is essential for long-term agricultural resilience.

Table 14: Determinants of choice of adaptation strategies

Covariates	Livelihood diversification	Soil and water conservation	Chemical fertilizer	Irrigation
Sex	0.49***(0.16)	0.21(0.21)	-0.00(0.21)	0.04(0.20)
Education	-0.01(0.02)	0.09***(0.02)	0.09***(0.02)	-0.01(0.02)
Family size	0.10***(0.04)	0.04(0.05)	0.17***(0.05)	0.12***(0.04)
Land size	0.10(0.14)	-0.36*(0.18)	-0.27*(0.15)	-0.05(0.15)
Farm income	0.00*(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)
Credit access	-0.06(0.25)	1.31***(0.37)	0.59**(0.26)	1.18***(0.26)
Market distance	0.00(0.00)	0.00(0.00)	-0.01**(0.00)	-0.01**(0.00)
Road distance	0.02(0.02)	0.01(0.02)	-0.03*(0.02)	-0.04**(0.02)
Perceived productivity	0.43**(0.17)	1.00***(0.19)	1.65***(0.21)	0.66***(0.20)
Climate knowledge	-0.02(0.17)	1.21***(0.22)	0.91***(0.27)	-0.04(0.21)
Land fragmentation	0.05(0.05)	- 0.17***(0.06)	-0.11**(0.06)	0.02(0.05)
Extension contact	0.10***(0.02)	0.09***(0.02)	0.10***(0.02)	-0.01(0.02)
Age	-0.00(0.01)	0.01(0.01)	0.01(0.01)	- 0.02***(0.01)
Livestock owned	0.02(0.01)	0.00(0.02)	0.01(0.02)	0.02*(0.01)

Constant	-1.42***(0.30)	-3.11***(0.41)	-4.24***(0.48)	-1.50***(0.35)
Log-likelihood	-564.495			
Wald chi2(56)	348.52			
Prob > chi2	0.000			
Number of obs.	385			

4.2.3. Determinants of Food Security Status of the Farm Households

Logit model was used to identify factors affecting food security status of the farm households in the study area. Results provided in Table 15 indicate that age, family size, farm income, market distance, road distance, climate change knowledge, extension contact, land fragmentation, and adaptation are the statistically significant factors affecting the food security status of the farm households in the study area at less than 10% probability levels. Age, family size, market distance, road distance, and land fragmentation affect the food security status of the farm households significantly and negatively while farm income, climate change knowledge, extension contact, climate change information, and adoption of climate change adaptation strategy/ies affects it significantly and positively at less than 10% probability levels. The discussion about the significant variables is presented below.

Age of the household head: The results indicate that age negatively and significantly affects food security status at the household level, with a 5% probability level (see Table 15). The negative coefficient suggests that as the age of the farm household head increases, the probability of achieving food security decreases. This trend implies that older farmers may encounter difficulties in affording necessary labor for farming and securing alternative sources of income, which can lead to increased food insecurity. Specifically, keeping all other factors constant, each additional year in the age of the farmer decreases the likelihood of being food secure by 0.6%. This finding aligns with the research of Faustine (2016), which also highlights the challenges faced by older farmers in maintaining food security.

Several arguments can be made to support this observation. First, older farmers may have reduced physical stamina and energy levels, making it harder for them to engage in labor-intensive agricultural practices. This decline in physical capability can limit their productivity and ability to manage their farms effectively. Additionally, older farmers may be less inclined to adopt new technologies or farming methods that could enhance productivity, further exacerbating their vulnerability to food insecurity.

Moreover, older farmers often have fixed income sources, which may not keep pace with rising costs of inputs and labor, making it difficult for them to invest in their farms. In contrast, younger farmers may be more adaptable and willing to explore innovative farming practices, potentially leading to better food security outcomes. However, it is essential to consider that age can also bring valuable experience and knowledge, which can be beneficial in managing agricultural risks. Therefore, while the findings suggest a negative correlation between age and food security, targeted support and resources for older farmers, such as access to labor and training in modern agricultural practices, could help mitigate the risks associated with aging in the farming sector.

Family size: The results indicate that at a 10% probability level, family size negatively affects food security status at the household level (see Table 15). The negative correlation suggests that as family size increases, the probability of achieving food security decreases. This implies that farmers with larger families may struggle to provide adequate food for all members, leading to heightened food insecurity.

This finding aligns with the research conducted by Bekele et al. (2023), which also highlights the challenges faced by larger families in maintaining food security. Larger family sizes can place greater demands on resources, including food, income, and agricultural inputs. As a result, families may find it increasingly difficult to meet their nutritional needs, especially if their agricultural productivity does not keep pace with the growing number of dependents. However, this result contradicts the findings of Faustine (2016), who argue that larger families can contribute additional labor to farm production, potentially enhancing overall productivity and income. This perspective suggests that the benefits of increased labor availability may offset the challenges posed by larger family sizes.

Several arguments can be made to understand this discrepancy. While larger families may indeed provide more labor, they also require more resources to sustain that labor force. If the household's agricultural output is insufficient to meet the nutritional needs of all members, the potential labor advantage may not translate into improved food security. Additionally, larger families may face increased competition for limited resources, which can exacerbate food insecurity.

Furthermore, the context in which these families operate is crucial. For instance, in regions where agricultural productivity is low or where access to markets is limited, larger family sizes may become a liability rather than an asset. In such scenarios, targeted interventions that provide support to larger families—such as improved agricultural practices, access to markets, and nutritional education—could help mitigate the negative impacts of family size on food security. Ultimately, a nuanced understanding of family dynamics and resource availability is essential for addressing food security challenges effectively.

Extension contact: The frequency of extension contact is a crucial factor that positively and significantly influences the food security status of farm households, with a probability level of 1% (see Table 15). This finding indicates that households with more frequent interactions with extension agents are more likely to achieve food security compared to those with fewer contacts.

The positive impact of extension services can be attributed to the vital role that extension agents play in enhancing farm productivity and increasing household income. By providing farmers with essential information, training, and resources, extension agents help improve agricultural practices, leading to higher yields and better financial outcomes. Consequently, this increase in productivity directly contributes to improved food security. This result is consistent with the findings of Gaddisa and Addisu (2021) and Bekele et al. (2023), which also highlight the importance of extension services in promoting food security among farming households.

In summary, the evidence underscores the need for continued investment in agricultural extension services, as they are instrumental in empowering farmers with the knowledge and skills necessary to enhance their productivity and, ultimately, their food security. Ensuring that farmers have regular access to extension agents can foster sustainable agricultural practices and improve the overall well-being of rural communities.

Farm income: Farm income has a significant and positive effect on the food security status of farm households, with a probability level of 1%. Specifically, an increase in farm income by 1% enhances the probability of achieving food security by 10.5%, while holding all other factors constant. This finding suggests that when farmers experience economic success, their capacity to obtain nutritious food for their families improves substantially (Bekele et al., 2023).

Qualitative data further supports this quantitative finding. Many farmers report that higher income allows them to invest in better quality seeds, fertilizers, and irrigation systems, which in turn boosts crop yields. For instance, interviews with farmers reveal that those who have experienced increased income are more likely to diversify their crops, leading to a more balanced diet for their families.

Additionally, qualitative insights indicate that economically thriving farmers can afford to purchase food during lean seasons, ensuring a steady supply of nutritious options. Some respondents noted that increased income enables them to participate in local markets, where they can access a variety of food products that enhance their family's diet. Moreover, farmers highlighted the psychological benefits of financial stability, such as reduced stress and improved overall well-being, which can further contribute to food security. This combination of quantitative and qualitative findings underscores the critical role of farm income in enhancing food security, emphasizing the need for policies that support agricultural productivity and economic growth in rural areas.

Climate change knowledge: This variable has a positive and significant effect on the food security status of farm households, with a probability level of 10%. When all other factors are held constant, households with climate change knowledge experience a 13.3% increase in the likelihood of being food secure, as indicated by the marginal effect of 0.133 for this variable. Consequently, households equipped with climate change knowledge are more likely to achieve food security compared to those without such awareness.

The rationale behind this finding is that households possessing knowledge about climate change can proactively prepare for its impacts, thereby enhancing their agricultural output. By effectively utilizing available agricultural inputs and resources, these households can optimize their production practices.

Furthermore, this knowledge facilitates better adaptation strategies, which are crucial for maintaining food security in the face of climate variability. For instance, farmers who understand climate patterns may implement crop rotation or select more resilient crop varieties, leading to improved yields and reduced vulnerability to climate-related shocks. Additionally, qualitative data supports this conclusion, as many farmers reported that understanding climate change has empowered them to make informed decisions about planting times, irrigation practices, and resource management. This alignment of quantitative and qualitative findings highlights the importance of promoting climate change education and awareness as a means to enhance food security among farm households (Belay et al., 2022).

Market distance: The results indicate that the distance from the nearest market center negatively and significantly impacts household food security status, with a probability level of 5%. The negative coefficient suggests that for every kilometer a farmer must travel to reach the closest market center, the likelihood of achieving food security decreases. Specifically, when all other factors are held constant, the marginal effect value of -0.164 implies that the probability of being food secure is reduced by 16.4% for each additional kilometer traveled.

This decline in food security can be attributed to several factors associated with increased market distance. First, greater distances often lead to higher transaction costs, which can include transportation expenses, time spent traveling, and the potential for spoilage of perishable goods. These costs can deter farmers from accessing markets to sell their products or purchase necessary farm inputs, ultimately limiting their income and productivity. Moreover, farmers living farther from markets may struggle to obtain timely market information, which is crucial for making informed decisions about pricing and demand. This lack of access can result in missed opportunities to sell their produce at optimal prices or to invest in high-demand inputs, further exacerbating food insecurity. Qualitative data supports these findings, as many farmers report that long travel distances hinder their ability to engage in regular market activities. Interviews reveal that some farmers choose to sell their products at lower prices to local middlemen rather than incur the costs of traveling to distant markets. This situation not only affects their income but also limits their overall economic resilience.

In summary, the evidence underscores the importance of improving market accessibility for rural farmers. Enhancing infrastructure and reducing the distance to market centers could significantly bolster food security by lowering transaction costs, facilitating better access to information, and enabling farmers to maximize their agricultural potential (Gaddisa and Addisu, 2021; Bekele et al., 2023).

Road distance: The results indicate that the distance to the main road negatively and significantly impacts household food security status, with a probability level of 10%. The negative coefficient suggests that for every kilometer a farmer must travel to reach the main road, the likelihood of achieving food security decreases. Holding all other factors constant, the marginal effect of -0.061 implies that the probability of being food secure is reduced by 6.1% for each additional kilometer traveled.

This decline in food security can be attributed to increased transaction costs associated with accessing the main road. Farmers living farther from main roads may face higher expenses when transporting their products to market and bringing essential farm inputs back to their fields. These costs can limit their ability to sell produce at competitive prices and to invest in necessary resources, ultimately affecting their overall productivity and income.

Additionally, the remoteness from main roads can hinder farmers' access to vital information and services, such as agricultural extension support and market trends. This lack of accessibility can further exacerbate food insecurity by reducing farmers' capacity to make informed decisions about their agricultural practices. Qualitative data supports this conclusion, with many farmers expressing that long distances to main roads complicate their market participation. Interviews reveal that some farmers opt to sell their products locally at lower prices rather than incur the costs and time associated with traveling to more distant markets.

In summary, the evidence highlights the critical need for improved road infrastructure to enhance market access for rural farmers. By reducing the distance to main roads, it may be possible to lower transaction costs, improve access to information, and ultimately strengthen food security among farm households (Gaddisa and Addisu, 2021; Bekele et al., 2023).

Climate change information: This variable has a positive and significant effect on the food security status of farm households, with a probability level of 5%. Holding all other factors in the model constant, households with access to climate change information have an 18.6% greater likelihood of being food secure compared to those without such information. Consequently, households equipped with climate change knowledge are more likely to achieve food security than their counterparts. The rationale behind this finding is that households with climate change information can proactively prepare for environmental changes, enabling them to manage their farms more effectively and enhance productivity. Access to timely and accurate climate data empowers farmers to make informed decisions regarding planting schedules, irrigation practices, and crop selection, which can lead to improved yields.

As noted by Ojo et al. (2022), climate information, such as updated weather forecasts, is a crucial service provided to farmers. This information significantly contributes to the adoption of climate change adaptation strategies, allowing farmers to mitigate risks associated with climate variability and ultimately strengthen their food security. In summary, the evidence underscores the importance of disseminating climate change information to farmers. By enhancing access to this knowledge, agricultural stakeholders can help improve the resilience and food security of farming households.

Land fragmentation: The results indicate that land fragmentation significantly and negatively impacts the food security status of farm households, with a probability level of 10%. Specifically, for every additional plot of land a farmer owns, the likelihood of achieving food security decreases by 2.8%, while holding all other factors constant. This decline in food security can be attributed to the increased transaction costs associated with managing fragmented farmland. Households with multiple, dispersed plots may face challenges in efficiently moving between these locations to cultivate crops, monitor growth, and harvest produce. The logistical difficulties of managing several small plots can lead to inefficiencies in labor and resource allocation, ultimately resulting in lower agricultural productivity.

Moreover, fragmented land can complicate access to essential services, such as irrigation and pest control, which are more easily implemented on larger, contiguous plots. Farmers with fragmented land may also struggle to achieve economies of scale, making it harder to invest in improved agricultural practices or technologies that could enhance their yields. Qualitative data supports this argument, as many farmers report that managing multiple plots is time-consuming and often leads to missed opportunities for timely interventions in crop management. Interviews reveal that some farmers find it challenging to coordinate labor and resources effectively across their various plots, which can further exacerbate food insecurity. In summary, the evidence highlights the need for policies that address land fragmentation and promote more consolidated farming practices. By facilitating land consolidation and providing support for efficient land management, stakeholders can help improve food security among farm households (Tran and Vu, 2021).

Adaptation: The results indicate that households that have adopted climate change adaptation strategies (CCASs) are more food secure than those that have not. Holding all other factors in the model constant, a household that implements CCASs has a 19.1% higher likelihood of achieving food security compared to its non-adopting counterparts.

This finding underscores the critical role of adopting CCASs in enhancing the food security of smallholder farm households. By implementing these strategies, farmers can better manage the risks associated with climate variability, leading to improved resilience and productivity. For instance, adaptation measures such as improving irrigation practices, and employing soil and water conservation techniques can significantly mitigate the adverse effects of climate change. Moreover, the positive impact of adaptation strategies aligns with the findings of Tadesse and Alemayehu (2019) and Ojo et al. (2022), who also emphasize the importance of proactive measures in ensuring food security in the face of climate challenges. These studies highlight that households equipped with effective adaptation strategies are better positioned to respond to climate-related shocks, thereby securing their livelihoods and food sources.

In summary, the evidence strongly suggests that promoting the adoption of climate change adaptation strategies is essential for enhancing food security among smallholder farmers. By providing support and resources for these adaptations, policymakers and agricultural organizations can play a vital role in building resilience within vulnerable farming communities

Table 15: Determinants of farm households' food security status

Covariates	Coef.	Std. Err.	Z	P>z	Marginal effects
Sex	-0.245	0.312	-0.790	0.431	-0.057
Age	-0.025**	0.012	-2.020	0.043	-0.006
Education	-0.021	0.035	-0.600	0.548	-0.005
Family size	-0.140*	0.073	-1.910	0.055	-0.032
Farm income	0.458***	0.151	3.030	0.002	0.106
Climate knowledge	0.564*	0.340	-1.660	0.097	0.133
Market distance	-0.770**	0.358	-2.150	0.032	-0.164
Road distance	-0.265*	0.153	-1.740	0.083	-0.061

Climate change information	0.844**	0.367	2.300	0.021	0.186
Land fragmentation	-0.119*	0.062	-1.910	0.057	-0.028
Extension contact	0.111***	0.036	3.060	0.002	0.026
Adaptation	0.916**	0.400	2.290	0.022	0.191
Constant	-3.406**	1.345	-2.530	0.011	

4.2.4. Impact of Adaptation on Food Security of Farm Households

4.2.4.1. Determinants of adoption of climate change adaptation strategies and food security status

The second column of Table 16 presents the results of the selection equation representing the determinants of adaptation. Results show that male headed households are more likely to adopt CCASs than female-headed households. This result concurs with the findings of the studies by Adzawla et al. (2019) and Jin et al. (2015) who argue that there is evidence of gender differences in climate vulnerability, decision-making, and access to resources. The education level of the head has a positive and significant effect on adaptation because educated farmers are more likely to be aware of climate change and agricultural innovations and make informed decisions (Feinstein and Mach, 2019). Earlier studies by Deressa et al. (2009) from Ethiopia, Alam et al. (2016) from Bangladesh, and Khanal et al. (2018) from Nepal found similar results. Results show that farm households with access to credit are more likely to adopt CCASs compared to others. This result is consistent with the findings of Khanal et al. (2018) and Di Falco et al. (2011) who argue that access to credit will lessen the financial constraints of the farm households thereby improve adaptation. Similarly, our finding suggests that farmers who have frequent contacts with extension agents are more likely to adopt CCASs, maybe because extension contact enhances farmers awareness about climate change impacts and hence adaptation. This is in line with the results of Khanal et al. (2018), Deressa et al. (2009) and Hassan and Nhemachena (2008).

Interestingly, the effect of knowledge of climate change is statistically significant and positive, which is in line with the results of other studies (Alam et al., 2016; Alauddin and Sarker, 2014; Deressa et al., 2009). This might be related to the fact that adaptation is the local response to climate stimuli as argued by Belay et al. (2022). Family size had increased adaptation against the adverse impact of climate change which might be due to the existence of a large number of active household members and/or the concern about food insecurity caused by climate change stresses in large families than others. This result confirms the results of Marie et al. (2020), Belay et al. (2017), and Deressa et al. (2014).

The significant positive effect of farm income on adaptation indicates the capital investment need of CCASs (Marie et al., 2020). Farmers with large farm sizes are less likely to adopt CCASs as large farms require high investment as argued by Aboye and Kinsella (2023) and Zekari et al. (2022). Marital status (Being married), plays a significant role in adaptation, as it promotes pool of resources and/or due to their responsibility to feed their families as argued by Asare-Nuamah and Amungwa (2021). Perceived productivity has a significant positive impact on adaptation as a positive perception that adoption of CCASs enhances farm productivity will lead to adoption of technologies. Credit access enhances adaptation as it involves capital outlays, mostly constrained in supply in developing countries (Ojo and Baiyegunhi, 2020).

The significant and negative effect of land fragmentation on food security of adapter households could be due to high transaction and management costs associated with fragmented farmlands compared to others. This is in line with the results of Tran and Vu (2021) who argue that land fragmentation adversely affects farm production because fragmentation not only prevents farmers from using modern, mechanized equipment, such as tractors and harvesters but also prevents the adoption of high-value crops that can only be cultivated on a large scale.

Family size, credit access, and distance to the road have significant negative effects on the food security of adapter households. The result for family size could be due to the high dependency ratio in large family (Mebrie and Ashagrie, 2023; Agidew and Singh, 2018), for credit access could be using credit for non-productive activities (Adgo et al., 2019) and for road distance could be the limited production of commercial crops, reduced market access, inefficient delivery of farm inputs and increased transportation costs (Wudad et al., 2021). The significant and positive effect of farm income and extension contacts on food security for adapters could be that higher income increases access to food (Babatunde and Qaim, 2009) and better extension access enables accessing training, fertilizer, chemicals and seeds, all of which contributes to increased agricultural productivity and hence food security (Woleba et al., 2023). Sex of the head and extension contacts significantly and positively determine food security of non-adapters while road distance affects it significantly and negatively as expected (Table 16).

4.2.4.2. Impact of adoption of climate change adaptation strategies on farm households' food security

The impact of climate change adaptation strategies on food security was analyzed by four approaches. First, we compare the average Daily Calorie Intake (DCI) of adapter and non-adapter households using a t-test. The results show that the average DCI of adapters is significantly higher than non-adapters (Table 16). Second, we estimate the OLS model of DCI that includes the adoption of CCASs as a dummy variable, taking the value 1 if the farming households applied at least one adaptation strategy in response to climate change stresses and 0 otherwise. Results show that the impact of adaptation on DCI is positive but insignificant (Second row of Table 16). Third, the PSM method was used to estimate the impact of adaptation on food security (Table 16). However, all the above approaches can be misleading and should be avoided in evaluating the impact of adaptation on food security as they assume that adaptation is exogenously determined while it is a potentially an endogenous variable (Di Falco and Veronesi, 2013). The difference in DCI may indeed be caused by unobservable characteristics of farming households.

In the fourth approach, we employed the ESR model to account for the endogeneity problem due to unobserved heterogeneity. ESR model was estimated using the Full Information Maximum Likelihood (FIML) approach which derives both the selection and outcome equations jointly. The first stage of the estimation of the ESR model is the selection equation which identifies the determinants of adaptation while the second stage of the estimation, identifies the sources of food security differentials among adapters and non-adapters. The second stage of the FIML also shows that the estimated correlation coefficient ρ_A between adapters and the outcome variable, namely food security and correlation coefficient ρ_N between non-adapters and food security. The significant negative and positive coefficients of ρ_A and ρ_N respectively imply that the hypothesis of absence of sample selectivity bias in the model may be rejected. These findings suggest that both observed and unobserved factors influence households adopting climate change adaptation strategies and the outcome variable given adaptation.

Moreover, the test of goodness-of-fit measure indicate that the selected covariates provide good estimate of the conditional density of adaptation and joint significance of explanatory variables with (Wald $\chi2=66.73$, $P<0.00$). The likelihood ratio test result for joint independence of the three food security equations (LR χ^2=10.08, P<0.00) indicated that the error terms in equation (3) and (4) were correlated and ignoring them could lead to biased results. Therefore, the use of the ESR models could reduce these biases.

The results of the correlation coefficients ρ_A = -0.64 and ρ_N = 0.62 for the food security equations showed that ρ_A was negative while ρ_N was positive and significantly different from zero (Table 16), which suggested that adopter farm households had higher food security status than the random farm household in the sample and the significance of ρ_N suggest that non-adapters would have better DCI than the random farm household, indicating that there was heterogeneity between the two groups.

Prior knowledge about climate change was used as exclusion variable in the selection equation and it was found to have positive and significant effect on food security measured in terms DCI.

Table 16: ESR model results for adaptation and impact of adaptation on food security

Explanatory variables	OLS	PSM	ESR		
			Adaptation (1/0)	Food security (DCI)	
				Adapters	Non-adapters
Sex	88.56	0.57***	0.45**	-297.05*	445.82*
	(127.67)	(0.21)	(0.21)	(159.82)	(257.58)
Marital status					
Married	-62.10	0.89**	1.10***	-102.11	201.52
	(200.83)	(0.40)	(0.39)	(249.88)	(429.60)
Divorced	-298.96	0.54	0.77	-477.32	-574.57
	(340.56)	(0.64)	(0.66)	(442.10)	(759.07)
Widowed	-376.09	0.12	0.89	29.65	-348.27
	(372.91)	(0.84)	(0.80)	(497.31)	(682.61)
Land fragmentation	-63.73*	0.24***	0.28***	-66.89*	-58.72
	(36.33)	(0.09)	(0.09)	(39.26)	(134.50)
Education level	3.31	0.04	0.06*	12.26	-80.30
	(15.01)	(0.03)	(0.03)	(17.45)	(50.89)

Family size	-69.53**	0.09*	0.12**	-75.70**	15.64
	(28.39)	(0.05)	(0.05)	(34.08)	(63.92)
Dependency ratio	-88.14	-0.12	-0.23	-135.51	844.61
	(178.19)	(0.31)	(0.29)	(185.82)	(743.09)
Farm size	-191.81*	-0.26	-0.34*	-163.21	-338.84
	(105.40)	(0.20)	(0.20)	(121.58)	(280.14)
Perceived	-176.00	1.28***	1.37***	-191.59	-400.52
productivity	(149.10)	(0.39)	(0.37)	(153.25)	(985.18)
Farm income	0.01**	0.00	0.00	0.01***	0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.01)
Credit access	-189.36	1.79***	1.60***	-492.91**	16.07
	(211.12)	(0.62)	(0.62)	(230.68)	(859.58)
Distance to road	-22.80**	0.20	0.15	-21.72**	-343.83**
	(10.44)	(0.10)	(0.11)	(10.64)	(165.97)
Distance to market	1.20	0.01	0.01	2.64	-6.54
	(2.16)	(0.00)	(0.00)	(2.30)	(9.13)
Social	77.96	0.08	-0.14	-269.15	431.43
participation	(191.85)	(0.32)	(0.32)	(281.26)	(349.11)
Extension contacts	83.98***	0.17***	0.16***	53.78***	133.46**
	(15.63)	(0.03)	(0.03)	(18.13)	(53.26)
Livestock owned	1.96	0.03	0.03*	-6.44	73.65**
	(9.39)	(0.02)	(0.02)	(10.27)	(30.36)
Knowledge of	-71.69	0.91***	1.03***		
climate change	(127.43)	(0.21)	(0.19)		
Adaptation	184.71				
	(156.76)				
Constant	2674.16***	-3.29***	-3.44***	3890.67***	1158.03
	(271.97)	(0.59)	(0.60)	(453.70)	(757.63)
σ_A				1038.77***	
				(52.05)	
σ_N					1042.10***
					(119.92)
ρ_A				-0.64***	

				(0.15)	
ρ_N					0.62***
					(0.24)
Wald chi2(15)			66.73***		
Pseudo-R^2		0.49			
Log-likelihood		-112.97	-3274.53		
LR test		218.77***	10.08***		
Number of observations	385	385	385	282	103

The results presented in columns (3) and (4) of Table 16 account for the endogenous switching in the FS function. An interesting finding is the signs and significances of the covariance terms ρ_A and ρ_N. The results show that the covariance terms for the adapters and non-adapters are statistically significant, indicating that self-selection occurred in adaptation. Thus, adaptation to climate change may not have the same effect on non-adapters, if they choose to adapt (Abdulai and Huffman, 2014; Lokshin and Sajaia, 2004). Moreover, the differences in the coefficients of the food security equations between the adapters and non-adapters suggest the presence of heterogeneity in the sample. That is, the significant roles that extension contact and distance to road play in explaining higher food security for both adapters and non-adapters, but the differentiated impacts of sex on the food security of adapters and non-adapters are indications of the presence of heterogeneity in the sample.

The signs and significance of the covariance terms (ρ_A and ρ_N) show that self-selection occurred in the decision to adopt CCASs. This implies adoption of CCASs may not have the same effect on food security of farm households if they choose to adopt CCASs (Abdulai and Huffman, 2014). The negative sign indicates a positive bias, suggesting that non-adapter farmers with above average DCI have a higher probability of not adopting CCASs. This finding is consistent with earlier studies by Barrett et al. (2012), Abdulai and Binder (2006), Abdulai and Huffman (2014) but contrasts with the findings by Kabunga et al. (2012).

The statistically significant covariance estimate for non-adapters suggests that in the absence of adoption of CCASs, there would be a significant difference in the average DCI of adapters and non-adapters caused by unobservable factors. The necessary conditions for consistency are also fulfilled, since $\rho_A < \rho_N$ indicates that adapters obtained higher DCI than they would have if they did not adopt CCASs (Lokshin and Sajaia, 2004).)

4.2.4.3. Treatment and heterogeneity effects of adaptation on food security

Table 17 presents the expected farmers' food security status measured in DCI under actual and counterfactual conditions and the estimated results of the average treatment effects and base heterogeneity effects. Cells (a) and (b) represent the expected food security observed in the sample. Cell (c) represents the expected food security of the adapters if they had decided not to adapt, and cell (d) represents the expected food security of the non-adapters if they decided to adapt. Adopters would have DCI of 272.87/day/AE (11.6%) less if they had not adapted. Similarly, non-adopters would have DCI of 504.61/day/AE (12.8%) higher if they had adapted. Our result is comparable with the results of Zakari et al. (2022) who found that adapters have 7% to 9% more chance to be food secure compared to non-adapters.

The transitional heterogeneity effect (TH) for the adoption of CCASs is positive and significant, implying that the effect of adoption of CCASs is even greater for the adapters compared to non-adapters (Sarma and Rahman, 2020).

Table 17: Impact of adaptation on expected food security, treatment and heterogeneity effects

Sub-samples	Decision stage		Treatment effects
	To adapt	Not to adapt	
Adopters	(a) 2623.21	(c) 2350.34	ATT = 272.87***
Non-adopters	(d) 3440.03	(b) 3944.64	ATU = -504.61**
Heterogeneity effects	BH_1 = -816.82	BH_2 = -1,594.30	TH = 777.48***

Note: *** and ** represent significant at the 1% and 5% levels respectively.

4.2.5. Linkages among Farmers' Knowledge, Adaptation and Food Security

Table 18 shows the estimation results on the linkages between farm households' knowledge of climate change, adaptation strategies, and food security status using the trivariate probit seemingly unrelated regression model. The model's Breusch-Pagan test of independence: chi2

(3) = 124.871, Pr = 0.000 shows that residuals of the equations were positively and significantly correlated at less than 1% probability level. This shows that the null hypothesis which assumes that there are no correlations between the residuals of the three equations is strongly rejected at less than 1% probability level. This implies that there a strong interdependence between farm households' climate change knowledge, food security status, and the adoption of adaptation strategies against the adverse effects of climate change. Hence, the use of a multivariate (trivariate) probit model is justified to determine factors behind the interdependence of food insecurity, climate change knowledge and adaptation of smallholder farmers in the study area.

The simulation results show that the sex of the household head, household income, education level, marital status and access to credit services significantly and positively affect their interlinkages while the age of the household head and market distance significantly and negatively affect it (Table 18). Moreover, sex, agricultural income, access to credit, and education level significantly and positively affected the adoption of adaptation strategies. However, non-agricultural income, marital status, and education level significantly and positively affected knowledge about climate change while age the household head and market distance affected farm households it negatively and significantly affects it. Finally, farm households' total agricultural income and access to credit affected the food security of the farm households positively and significantly in the study area.

Table 18: Results of trivariate probit seemingly unrelated regression model for farm households' knowledge of climate change, adaptation, and food security

Explanatory variables	Adaptation strategy	Knowledge of climate change	Food security
Age	0.01(0.01)	-0.02***(0.01)	0.01 (0.01
Sex	0.42*** (0.07)	-0.12(0.17)	0.05 (0.17)
Family size	-0.03 (0.04)	0.03 (0.04)	0.03 (0.04)
Dependency ratio	-0.02(0.22)	-0.31(0.23)	-0.11 (0.26)
Agricultural income	0.34*(0.20)	0.27(0.19)	0.50***(0.19)
Non-agricultural income	0.01 (0.02)	2.13*** (0.86)	0.01 (0.01)
Access to credit	0.50 **(025)	0.21(0.26)	0.47* (0.26)

Marital status	-0.29 (0.27)	0.28***(0.25)	-0.95 (0.25)
Education level	0.42***(0.17)	0.59***(0.17)	-0.32 (0.16)
Market distance	-1.24 (0.82)	-1.83**(0.82)	-1.85 (0.90)
Road distance	-4.77 (286)	4.58(165.17)	4.12 (172)
Constant	-1.15 (0.35)	0.77**(0.35)	-0.37 (035)
Dependent variable residuals	**Correlation matrix of residuals**		
Knowledge of climate change			
Food security	0.429		
Adaptation	0.789	0.897	
Breusch-Pagan test of independence: chi2(3) = 124.871, Pr = 0.0000			

Source: Own computation, 2023

5. SUMMARY, CONCLUSION AND POLICY IMPLICATIONS

This chapter summarizes the study results, makes conclusions based on the key findings of the study, forward important policy implications, presents the contribution of the study, and suggests some of the future research directions to fill the potential delimitations and advance the study.

5.1. Summary

Climate change and variability is becoming the most critical and negatively affecting the Ethiopian agricultural activities in the Eastern Ethiopia Dire Dawa city administration in particular. It is believed that farmers' knowledge of climate change, selection of adaptation strategies, the effect of the adaptation strategies on food security, and their linkages are important to the agricultural stakeholders specifically for policy formulation in the mitigation of the climate change negative impact and development of climate resilient agricultural economy and community. This study assesses knowledge of climate change and variability, adaptation, and the effect of adaptation on food security and their linkages in the study area. In a biophysically and socioeconomically diverse country like Ethiopia, a local-specific climate change and variability-related study provides more information for policymakers to design future effective policy interventions.

This study initiated to fill the prevalent scientific information gap focusing on the three themes. The first specific objective estimates households' knowledge level of climate change and variability and its determinants. The second specific objective measure households' adaptation strategies and its influencing factors. The third specific objective identifies the effect of climate change adaptation on food security; and finally, the fifth specific objective assess the linkages between farmer households' knowledge of climate change, adaptation strategies, and adaptation effect on food security linkages. The study used primary cross-sectional data collected from 385 farm households using multistage random sampling procedures from the four randomly selected clusters of the Dire Dawa administration, Eastern Ethiopia.

The result of the descriptive statistics showed that 7.75%, 38.64%, 23.244%, and 30.35% of the sampled farm households had very low, low, medium and high climate change knowledge, respectively. Furthermore, the majority of the sampled households (59.06%) were food insecure in the study area.

The result of the ordered logistic regression model showed that sex, age, marital status, extension contact, climate change information, credit access and land fragmentation are the significant factors affecting climate change knowledge at different probability levels in the study area.

The result of the MVP regression model identified factors affecting key adaptation strategies to the impacts climate change. The Breusch–Pagan test of independency is significant implying that the null hypothesis assumes all the residuals of the adaptation strategies are independently rejected at less than 1% significance levels. Therefore, all the pairwise combinations of the four adaptation strategic equations error terms positively and significantly correlated imply that the strategies were complementary, or they have a synergetic effect on each other. This means the adaptation of one strategy has a spillover effect on another strategy. The post-MVPM estimation of the joint probability of success and failure indicated that farmers have a 26% and 9% probability of failure and success of adopting neither of the strategies and all the strategies, respectively. Besides, the result of linear prediction showed that livelihood diversification was the dominantly adopted strategy followed by soil and water conservation in the study area.

Farmers used both autonomous (LHD) and public adaptation strategies (SWC, CF and SSI) where the latter strategies are complementary in the study area. Results of the MVP model indicate that the major factors that influenced farmers' adaptation choices statistically and significantly were sex, educational level, family size, farm income, land size, extension contact, climate change knowledge, age, livestock owned, market distance, land fragmentation, perceived productivity, road distance, and access to credit services.

Logit model results on the determinants of food security status show that age, family size, market distance, road distance and land fragmentation affect the food security status of the farm households significantly and negatively while farm income, climate change knowledge, extension contact, climate change information and adoption of climate change adaptation strategy/ies affect it significantly and positively at less than 10% probability levels.

The result of the Endogenous Switching Regression model showed that adaptation significantly improved (11.6%) the food security status of the adopter farm households. Finally, the result of the study showed that there is a strong interdependence between farmers' knowledge of climate change, food security, and adaptation decisions in the study area.

5.2. Conclusion

The majority of the farm households in the study area are food insecure (59%) and have knowledge of the impacts of climate change. Descriptive statistics and OLM results revealed that farmers have differentiated knowledge of climate change and variability ranging from poor to high knowledge which has been affected by social, economic, biophysical and institutional factors. Farm households headed by male and young farmers, which are married, have frequent contact with extension agents, have access to climate change information and credit, and have non-fragmented plots have better climate change related knowledge than others.

To reverse the adverse impacts of climate change farm households in the study area adopted soil and water conservation practices, use chemical fertilizers, livelihood diversification and small-scale irrigation as the major adaptation strategies. Results show that majority of farm households (58.79%) adopted diversifying their livelihoods to other sub-sectors such as charcoal sales, petty trade and others, followed by 44.88% who adopted soil and conservation structure, 32.55% adopted chemical fertilizers, and 19.95% adopted small-scale irrigation to adapt to the adverse impacts of climate change. Finally, 26.51% of the farm households did not adopt any of the above-mentioned adaptation strategies implying the need for educating these farm households to adopt climate smart adaptation strategies for coping the adverse impact of climate change. The MVPM result indicated that farm households headed by male, having large family, who perceive improved productivity and have frequent contact with extension agents are highly likely to adopt livelihood diversification strategy; farm household heads who are educated, own small farm, have access to credit, who perceive improved productivity, have frequent contact with extension agents, have climate knowledge and with few fragmented lands are highly likely to adopt soil and water conservation strategy; farm household heads who are educated, have large family, have small farm, have access to credit, closer to market and road, have frequent contact with extension agents, have climate knowledge and with few fragmented lands are highly likely to adopt chemical fertilizer; farm household heads who are young, have large family, have small farm, have access to credit, who perceive improved productivity, closer to market and road and own large herd size are highly likely to adopt small-scale irrigation as an adaptation strategy to cope up with the adverse impacts of climate change.

The result further indicated that household food security status was influenced by a wide range of factors such as age, family size, market distance, road distance and land fragmentation significantly and negatively while farm income, climate change knowledge, extension contact, climate change information and adoption of climate change adaptation strategy/ies were positively associated with food security status of households.

Using an ESR model this study evaluated whether or not adoption of either of these adaptation strategies or in combination improved their food security situations in drought prone rural DDA of Ethiopia disproportionately affected by climate change. The model revealed that sex, marital status, land fragmentation, education level, family size, farm size, credit access, extension contacts and livestock ownership are the most important factors of adaptation while sex, land fragmentation, family size, farm income, credit access, road distance and extension contacts are the significant determinants of food security measured in daily calorie intake per AE per day of the farm households in the study area. Except for farm size for adaptation and credit access for food security of adapters, the coefficients of all variables are in line with the hypothesis. Farmers with large farm size are less likely to adopt as it requires higher investment and farmers with access to credit are less likely to be food secure as the credit may not be used for farm investment. Two important conclusions are drawn from this study. First, adapters have benefited from improved food security status. Second, the model results showed a systematic difference (heterogeneity) between adapters and non-adapters which was revealed by sex of the head variable. For instance, being male head is associated with a lower likelihood of food security for adapters and a higher likelihood of food security for non-adapters. Moreover, land fragmentation and family size have the likelihood of reducing food security for adapters, but not for non-adapters.

The result of the seemingly unrelated trivariate probit regression model showed that farmers' knowledge, adaptation, and food security significantly interdependent is the agricultural system problems in the study area. This implies that assuming climate change and variability the root cause of the agricultural problem, improving it will improve the others as agricultural system.

5.3. Policy Implications

From the study findings, a large number of implications can be drawn. However, based on the specific objectives of the study, the following key policy suggestions are forwarded:

1. It is found that farmers' knowledge of climate change varied considerably among the among farm households and determined by various household, farm and institutional factors. The study indicated that a considerable number of farmers across the study area had low level of knowledge about climate change impact. Therefore, policymakers and local development practitioners should improve farmers' knowledge of climate change and variability, and its consequential impacts on agricultural productivity, farm households food security, poverty reduction, local and national peace and security and national economic growth. Provision of climate related education at the local can improve farmers knowledge and enable them use climate smart agricultural practices or strategies. Therefore, based on the results from factors affecting farmers' knowledge of climate change and variability, promotion of gender equality, focus on older and unmarried farm households, access to information and finance, promotion of extension services and land consolidation should be targeted by policy makers. Improving climate information system based on the very sub specific metrological system in a way that can provide early warning to flood and drought including long term pattern and even forecasting future scenarios with possible climate smart agricultural practices.

2. Farmers adopt locally available adaptation strategies that were common to their ancestors. Policymakers, local development planners, and development partners should promote local farmers' adaption strategies based on the significant factors affecting the choice of adaptation strategies. Provision of information on the adverse impacts of climate change on agriculture, provisions of credit and extension services, infrastructure, land consolidation and asset formation improve farm households' choice of adaptation strategies in the study area implying the need for creating access to information, provision of credit and extension services for improving the resilience capacity of farmers at the local levels.

Farmers were more likely to fail than to succeed in adopting all the adaptation strategies jointly. Major changes within the farming community are required to improve farm households' livelihood since wealth and its correlates on top of farmers' gender and age had an influence on choice of adaptation measures. Policy making should focus on empowering female farmers by creating conducive environment to access credit, information and extension service associated with climate change and agriculture. In addition, policy makers and development practitioners should put emphasis on instituting local meteorology stations and community radio services to deliver up to date information on climate, the productivity enhancement of adaptation and knowledge about climate change. Providing vocational training on climate related issues would also speedup farmers' climate change knowledge and adaptation choices. Extension agents in the community should be proficient on climate change impacts to provide sufficient advice and information for farmers. The public agricultural extension system needs to include climate related information in its extension packages provided to farmers at the local levels.

3. Adoption of climate change adaptation strategies positively and significantly improved food security of the farm households in the study area. Three important policy implications are drawn from this analysis. First, the differentiated effect of some factors on adapters and non-adapters implies the importance of considering these heterogeneities during intervention. Second, ownership of livestock and knowledge of climate change played a key role in determining adaptation, which implies that the planning and implementation of adaptation strategies should enhance and consider asset formation and devising mechanisms to increase the awareness of farmers about the impacts of climate change. This increases adaptation and hence food security of the farm households. Third, farm size and access to credit are negatively associated with adaptation and food security, respectively. Therefore, interventions should devise mechanisms to provide education for farmers with large farm size on how they can use their farm for enhancing their food security using climate smart agricultural practices. Farmers need to be educated to use the credit they receive to adopt climate adaptation strategies so that they can withstand the climate variability and improve their food security in the area. or

4. Addressing the systematic linkages between knowledge of climate change, food security and adaptation in the face of climate change and variability adversely affecting the agricultural system of the study area is crucial for policy making. Results show the statistically significant positive synergy between the three factors and the need to take appropriate policy measures that simultaneously address them. The agricultural office at the local level and other relevant stakeholders need to target increasing the awareness about climate change for enhancing food security and adoption of climate adaptation strategies in the area.

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7. APPENDICES

7.1. Appendix A Tables

Appendix Table 1. Conversion factors used to estimate tropical livestock unit (TLU) equivalents

Animal category	TLU
Calf	0.50
Donkey (young)	0.35
Weaned Calf	0.34
Camel	1.25
Heifer	0.75
Sheep and Goat (adult)	0.13
Cow and Ox	1.00
Sheep and Goat (young)	0.06
Horse	1.10
Chicken	0.013
Donkey (adult)	0.70

Source: FAO (2004)

Appendix Table 2. Conversion factors of food items consumed by sample households

Food items	Unit	kilocalorie (kcal)	Proportion of Consumption (%)
Barley	Kg	3723	0.00
Maize	Kg	3751	31.45
Sorghum	Kg	3805	31.14
Teff	Kg	3589	0.35
Wheat	Kg	3623	20.37
Irish potato	Kg	1037	1.34
Sweet potato	Kg	1360	0.06
Lentil	Kg	3522	0.18
Beans	Kg	3514	2.89

Peas	Kg	3553	0.50
Onion	Kg	713	0.65
Pepper	Kg	933	0.00
Beef	Kg	1148	0.09
Milk	Kg	737	1.23
Egg	No.	61	0.04
Sugar	Kg	3850	2.74
Butter	Kg	7364	0.00
Edible oil	Litter	8964	6.93
Vetch	Kg	3470	0.00
Coffee	Kg	1103	0.04

Sources: Ethiopian Health and Nutrition Research Institute (1998)

Appendix Table 3. Multicollinearity test for variables used in climate change knowledge

Variable	VIF
Sex	1.26
Age	2.56
Marital status	3.24
Education	1.34
Family size	1.20
Farm income	4.21
Extension contact	2.23
Climate change information	3.02
Credit access	2.78
Market distance	4.10
Land fragmentation	3.21
Social participation	1.45
Mean VIF	2.55

Appendix Table 4. Multicollinearity test for variables used in adoption of CCASs

Variable	VIF

Fragmentation	3.15
Livestock owned	2.61
Age	1.62
Family size	1.51
Land size	1.51
Farm income	1.44
Perceived productivity	1.42
Climate knowledge	1.33
Credit access	1.25
Sex	1.24
Extension contact	1.20
Education	1.19
Market distance	1.15
Road distance	1.04
Mean VIF	1.55

Appendix Table 5. Heteroscedasticity test result for choices of CCASs

. hettest

Breusch-Pagan / Cook-Weisberg test for heteroscedasticity

Ho: Constant variance

Variables: fitted values of vulnerability index

chi2(1) = 0.20

Prob > chi2 = 0.66

Appendix Table 6. Test of parallel lines for OLM

Model	-2 Log Likelihood	Chi-Square	Df	Sig.
Null Hypothesis	222.16			
General	208.17	13.99	16	0.56

Null hypothesis: The slope coefficients are the same across response categories.

7.2. Appendix B Household Questionnaire

Prepared by Girma Admasu

PhD student, Haramaya University, college of Agriculture and Environmental Sciences, School of Rural Development and Agricultural Innovation and Commercialization and Rural Institutions Programme.

This questionnaire is used for the research survey entitled "Smallholder Farmers' Knowledge on Climate Change adaptation Strategies and Their Impacts on Food Security in Dire Dawa City Administration, Eastern Ethiopia". The purpose of this questionnaire is to collect primary data that will help me in writing my dissertation. I ask for your kind cooperation and patience in answering the questions accurately and reliably. Your answers are anonymous and absolutely confidential, and only summary information will be given in the study results. I would like to thank you for your courage and kind answers.

Instruction for enumerators

1. Please administer this tool to the head of the household (spouse or child in case of a child-headed household).
2. Introduce yourself, greet warmly and tell the respondents the purpose of the study
3. Ask the respondent each question
4. Make sure that all questions are correctly filled before finishing each interview.

Information about the respondent		Information about the enumerator
Respondent's name:	____/______	Enumerator's name:

1. Farm Household Characteristics

1.1. Sex of the household head? 1. Male 0. Female

1.2. How old are you in years? _____________

1.3. To which ethnic group do you belong to? ______

1.4. What is your marital status? 1. Married, 2. Single, 3. Divorced, 4. Widowed

1.5. What is your education level in grade completed including read and write? _______

1.6. What is the number of members of your family? ___________

1.7. What is your household demographic structure? 1. Children (<=15) _____2. Family members between 15 and 64 __________c. Family members above 64 years___

1.8. Do you participate in local social organizations? 1. Yes, 0. No

1.9. If your answer is yes, in which of the following organization/s you participated (circle).

1. Afosha, 2. Mahiber, 3. Kebele administration, 4. Others, specify __________

2. Livelihood Strategies and Expenditures

2.1. What is your main source of livelihood? 1. Farming, 2. Non-farming, 3. Mixed

2.2. What are the sources and amount of your agricultural income last year (12 months) in the 2014/2015? Fill the following Table 1.

Table 1. Local family's main agricultural activities and their annual income contribution

S. N.	Economic activities	Birr	S. N.	Economic activities	Birr
1	Livestock production		5	Beekeeping	
2	Vegetables and fruits		6	Remittances	
3	Chat		7	Others (specify	
4	Coffee			Total	

2.3. If you participate in non-agricultural income generating activities in the past 12 months fill the following Table 2.

Table 2. Farm household's off/non-farm activities and their income contribution

S. N.	Economic activities	Estimated Birr per year

1	Charcoal making	
2	Handicraft	
3	Transportation business	
4	Casual labor	
5	Petty trade	
6	Beverages	
7	Mining (sand, quarry)	
8	Others (specify)	

2.4. What is your annual expenditure in Birr on the following items? 1. Food expense ____________2. School fee _____ 3. Cloth ___ 4. Agricultural inputs fee _______, 5. Medical fee ___6. Others (specify) ________ 7. Total _____

3. Farm Households Agricultural Land Related Information

3.1. Do you have a farm land? 1. Yes, 0. No

3.2. If your answer is yes in question 3.1, fill the following Table 3 about your land information.

Table 3. Farm household's land acquisition, use, security, conflict, plot and area information

3.2.1. Land acquisition	3.2.2. Land use	3.2.3. Security status	3.2.4. Presence of conflict	3.2.5. Number of plots you have	3.2.6. Area of each plot (ha)
1.Gov't allocation 2. Short term lease 3. Shared in 4. Inheritance 5. Others (specify)	Pastureland				
	Cropland				
	Forest land				
		1.Yes 0.No	1.Yes 0.No		

3.3. What is the number of years you reside in the area? ________ Years

4. Climate Change Knowledge

4.1. In your opinion, do you think the temperature on earth has been rising over the past decade? 1. Yes, 2. No, 3. I don't know

4.2. If yes to 4.1, what are the effects of rising temperatures? 1. Lower yields, 2. Make production more variable, 3. Put additional stress on livestock and poultry, 4. Others, specify_________________

4.3. In your opinion, do you think rainfall has been increasing over the past decade? 1. Yes, 2. No, 3. I don't know

4.4. If yes to 4.3, what do you think are the effects of heavy rainfall? 1. Increased soil erosion, 2. Nutrient loss, 3. Flooding, 4. Others, specify__________________

4.5. Do you think that extreme weather events (heavy rainfall, heavy precipitation, flood, etc) will become more frequent in the future? 1. Yes, 0. No

4.6. Do you know what climate change is? 1. Yes 0. No

4.7. How do you know whether the climate has changed or not? 1. Rising temperatures, 2. Heavy rainfall, 3. Flood, 4. Heavy precipitation, 5. Drought, 6. Others, specify_________

4.8. Would you please fill in the following table referring to farmer's knowledge about climate change?

Table 4. Climate change knowledge

Category	Indicators of climate knowledge	Strongly disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly agree (5)
Knowledge of causes	Climate change is caused mostly by human activities					
	Climate change is caused more or less equally by natural changes in the environment					

	and human activities					
Knowledge of consequences	Climate change will increase the negative public health impacts					
	Climate change will increase temperature and rainfall					
	Climate change will increase the droughts					
	Climate change will increase insects					

4.9. Do you have information about climate? 1. Yes, 0. No

4.10. If your answer to 4.9 is yes, what is your source of information about climate change? 1. Television, 2. Radio, 3. Newspaper, 4. Internet, 5. Development agents, 6. NGOs, 7. Others, specify____________

4.11. What do you think is the possible solution to mitigate the impacts of climate change on your agricultural activities and family welfare? ____

4.12. Whom do you think are the most vulnerable to the impact of climate change among communities in your area?____

5. **Farm Households Agricultural Production**

5.1. What is your crop production status in 2022/2023 production years? Fill the following Table

No.	5.1.1. Types of crops grown	5.1.2. Areas (ha/time)	5.1.3.Total output (quintals)	5.1.4. Did you observe your plot land yield reduction?	5.1.5. If your answer is yes in 5.1.4, what is the average percentage reduction in the last five years?
1	**Annual crops**				
1.1	Maize				
1.2	Wheat				
1.3	Sorghum				
1.4	Barley				
1.5	Pea				
1.6	Lentil				
1.7	Others (specify) ________				
2	**Vegetables and fruits**				
2.1	Cabbage				
2.2	Onion				
2.3	Beetroot				
2.4	Potato				
2.5	Tomato				
2.6	Papaya				
2.7	Banana				
2.8	Orange				
2.9	Chat				
2.10	Others (specify) ________				

5.2. Do you have livestock? 1. Yes, 0. No

5.3. If the response in question no 5.2 is yes, fill the following table

5.4.

Types of Animal	Number	Types of Animal	Number	Types of Animal	Number
Oxen		Donkey (adult)		Sheep (young)	
Cows		Donkey (young)		Goat (young)	
Heifers		Mule		Goat (adult)	
Calves		Horse		Chicken	
Weaned calves		Sheep (adult)			

What is your wealth status in the community based on the community wealth ranking criteria?

1. High, 2. Medium, 3. Low

6. Household Food Insecurity Information

6.1. Household food consumption from crops and livestock

Consumption items	Amount produced		Amount consumed from own production			Amount consumed from market purchase		
	Unit	Quantity	Quantity	Ave. unit price	Total expenditure(Birr)	Quantity	Ave. unit price	Total expenditure(Birr)
Cereals								
Wheat								
Barley								
Maize								
Teff								
Sorghum								
Total								
Pulses/Legumes								
Faba bean								
Field Pea								
Chick Pea								
Haricot bean								
Lentils								
Total								
Tuber and vegetable crops								

Potato								
Carrot								
Onions								
Cabbage								
Tomato								
Total								
Fruits								
Orange								
Papaya								
Avocado								
Mango								
Banana								
Total								
Livestock								
Milk								
Yogurt								
Cheese								
Butter								
Egg								
Honey								
Total								

6.2. Calorie acquisition (intake) questions

Could you please tell me how many days has the household eaten any food made from each food items in the last 7 days?

No.	Food groups	Food items	Unit	Total weekly consumption	Number of days eaten over the past 7 days
1	Cereals	Wheat	Kg		
		Barley	Kg		
		Maize	Kg		
		Teff	Kg		
		Sorghum	Kg		
2	Pulses/Legumes	Faba bean	Kg		
		Field pea	Kg		
		Lentil	Kg		
		Haricot bean	Kg		
		Chick pea	Kg		
3	Meat, Egg or Fish	Meat	Kg		
		Egg	Kg		

		Fish	Kg		
4	Dairy Products	Milk	Liter		
		Yogurt	Kg		
		Cheese	Kg		
5	Tubers and Vegetables	Potato	Kg		
		Carrot	Kg		
		Onion	Kg		
		Cabbage	Kg		
		Tomato	Kg		
6	Fruits	Orange	Kg		
		Papaya	Kg		
		Avocado	Kg		
		Mango	Kg		
		Banana	Kg		
7	Oil, fat or butter	Processed oil	liter		
		Fat	Kg		
		Butter	Liter		
8	Sugar, sugar product or honey	Sugar	Kg		
		Honey	Kg		

6.3. Summarized food consumption for 7 days

A. Household home prepared Food Consumption summary

List the food items prepared & consumed by the HH in the last 7 days in the house	The food items are prepared/made from	Amount in Kg/Liter/piece/cup/spoon	Value in Birr
1st day			
2nd day			
3rd day			
4th day			
5th day			
6th day			
7th day			

B. Household outside the home prepared Food Consumption summary

List the food items consumed by the HH outside the house in the last 7 days	The food items are prepared/made from	Amount in Kg/Liter/piece/cup/spoon	Value in Birr
1st day			

2nd day			
3rd day			
4th day			
5th day			
6th day			
7th day			

C. Household from gift/food aid/ Food Consumption summary

List the food items consumed by the HH consumed from gift/food aid in the last 7 days	The food items are prepared/made from	Amount in Kg/Liter/piece/cup/spoon	Value in Birr
1st day			
2nd day			
3rd day			
4th day			
5th day			
6th day			
7th day			

6.4. What do you think is the impact of climate change on your family welfare? 1. Food insecurity 2. Income 3. A decrease in crop and livestock production and productivity 5. Livestock death, water shortage 7. Land fertility 8. Others (specify) ______________

6.5. Do you think that your family is vulnerable to food insecurity due to the impact of climate change in the last 12 months? 1. Yes 0. No

6.6. If your answer is yes, how do you describe the level of food insecurity? 1. Minimal/None, 2. Stressed, 3. Crisis, 4. Emergency, 5. Catastrophe/Famine 6. Others (specify)_______________________

6.7. If. Your response in question 6.5 is no, do you produce enough food for your family? 1. Yes 0. No

6.8. What is your strategy to secure your food security to mitigate climate change impact? ___________

6.9. In addition to climate change, what are other factors causing your family vulnerable to food insecurity? 1. Livestock disease 2. Social peace and security (livestock robbery) 3. Floods 5. Others (specify) ______

7. Information on Climate Change Adaptation and Its Impacts

7.1. Do you know any adaptation strategies to the impact of climate change? 1. Yes, 0. No

7.2. If your answer is yes in 7.1, did you adopt any adaptation strategy? 1. Yes 0. No

7.3. If your answer is yes in 7.2, what are the adaptation strategies you have been implementing to reduce your food insecurity problem to the impact of climate change in order of your preference? Fill the following table.

S.No.	Adaptation strategies	Yes or No
1	Crop-livestock diversification	
2	Soil and water conservation	
3	Use of chemical fertilizer	
4	Livelihood diversification	
5	Crop type preference	
6	Animal preference	
7	Cropping season/sowing date	
8	Irrigation	
9	Others (specify)	

7.4. If your answer is no in 7.2, why you do not adopt any climate change adaptation strategy? 1. Shortage of labor 2. Lack of information 3. Lack of money 4. Shortage of land 5. Poor potential for irrigation 6. Lack of technical support 7. Lack of skills 8 Poor government support 9. Lack of awareness 10 shortage material 11. Others (specify) ______________

7.5. Do you have any constraints in climate change adaptation you have? 1. Yes, 0. No

7.6. If your answer is yes in 7.5, do you use adequate credit service? 1. Yes, 0. No

7.7. If your answer is yes, what is the amount of money you borrowed last year?_______Birr.

7.8. Do you have contact with extension agents? 1. Yes, 0. No

7.9. If yes to 5.8, how many times you contact DAs last year?____________

7.10. How far is the nearest market center from your residence? _____ walking hrs.

7.11. How far is the nearest main road from your farm? ____ Walking minutes.

7.12. How far is the nearest health center from your resident? _______ Walking hours

7.13. How far is the nearest veterinary service from your resident? _____ Walking hours

7.14. Are you aware of any modern climate change mitigation/ adaptation technology from any institution? 1. Yes, 0. No

7.15. If the answer to question 7.14 is yes, how do you rate the use of the technology/ies? 1. Excellent 2. Very good 3. Good 4. Satisfactory 5. Poor

7.16. Who will provide the technologies? 1. Government 2. NGOs 3. Research centers 4. University 5. Others (specify) ___________________

Thank you very much!

7.3. Appendix C Guiding Checklist Used for Focus Group Discussions

To conducted group discussion, group discus procedures will be maintained. At each selected kebeles one group discussion will be conducted. The leading researcher will lead the discussion. Photo graphs were taken for documentation. Introduce yourself and invite them each participates to introduce them, tell them the objective of the discussion and time it takes.

1) How do you understand climate?
2) What do we mean climate change?
3) How do we know climate change?
4) What causes climate change?
5) Who is responsible to climate change?
6) How significant is the climate change?
7) What should we do to mitigate/reduce climate change?
8) What is the impact of climate change?
9) Who is more vulnerable to the impact of climate change?
10) What are you adopting avoid the impact of climate change?
11) Who are adopting the strategies?
12) Are the strategies effective?
13) Do you thank those strategies have impact on food security?
14) What are the sources of the strategies?
15) You have any institutional support to mitigate climate change?

Thank you very much for your time and active participation during the discussion!