UNIVERSITY OF NAIROBI

Adoption of Climate-Smart Agricultural Practices Among Smallholder Farmers and Implications for Climate Change Adaptation in Southern Ethiopia

BY

Abrham Belay Mekonnen (I85/53726/2018)

A Thesis Submitted in Partial Fulfilment of The Requirements for the Degree of Doctor of Philosophy in Climate Change and Adaptation in the Department of Earth and Climate Sciences of The University of Nairobi

June 2024

PLAGIARISM STATEMENT

This thesis was written by me and in my own words, except paraphrased quotations from published and some unpublished sources which are clearly indicated and acknowledged. I am aware that the incorporation of material from other works or a paraphrase of such material without due acknowledgement will be treated as plagiarism, subject to the custom and usage of the subject, according to the University Regulation on Conduct of Examinations. The source of any picture, map or other illustrations is also indicated, as is the source, published or unpublished, any of material not resulting from my own experimentation, observation, or specimen-collecting.

Signature: ________ Date: 11/06/2024

Abrham Belay Mekonnen

This Thesis has been submitted for examination with our approval as University Supervisors:

________________________ Date: 18/06/2024

Signature

Prof. Christopher Oludhe

Department of Earth and Climate Sciences, Faculty of Science and Technology

University of Nairobi, PO Box 30197-00100, Nairobi, Kenya

____________ Date: 13/06/2024

Signature

Dr Lydia Olaka

Department of Geoscience and the Environment

Technical University of Kenya, PO Box 52428-00200, Nairobi, Kenya

________________ Date: 14/06/2024

Signature

Dr Philip Osano

Stockholm Environment Institute, World Agroforestry Centre, P.O. Box 30677, Nairobi, Kenya

____________________________ Date: 14/06/2024

Signature

Dr Zerihun Berhane

Center for African and Asian Studies, Addis Ababa University, P.O. Box: 1176, Addis Ababa, Ethiopia

DEDICATION

This Thesis is dedicated to my late parents Ato Belay Mekonnen, and W/o Abezath Tadesse, for their constant love and support, whom I missed too early.

ACKNOWLEDGMENT

First and foremost, I praise Almighty God, who has helped me to begin and complete this study. Holy Virgin Mary, Mother of God, may your intercession always be with me. I would like to express my heartfelt appreciation and gratitude to my supervisors, Professor Christopher Oludhe, Dr Philip Osano, Dr Lydia Olaka and Dr Zerihun Berhane for all the invaluable guidance, suggestions, and enthusiastic encouragement that I received throughout the research process. I would also like to thank Dr John Recha, Dr Teferi Demisie and Dr Dawit Solomon who gave me great feedback on some of the chapters of my thesis. I want thank Dr Alisher Mirzabaev and Professor Dr von Bruan, a distinguished professor at the Center for Development Research (ZEF), University of Bonn, Germany, for their insightful feedback and helpful advice on my research. I would like to express my deepest appreciation to Dr Yitagesu Tekle from the European Forest Institute in Bonn office for his consistent guidance, enthusiasm, and kind assistance throughout the process of writing my thesis. Thirdly, my thanks go to the agricultural and rural development offices in Doyogena district of southern Ethiopia which provided logistical support, made themselves available for interviews, and shared their perspectives during the fieldwork. In addition, my sincere gratitude goes to Mr Mesfin Desalegn, Mr Mesele Gintamo and Mr Tsegay Mathewos from InterAide France Ethiopia project team members who moderated the group discussions with the farmers and participated in the data collection process. My sincere gratitude goes to my colleagues Dr Girma Kelboro, Dr Tefera Belay, Dr Habtamu Tadesse, Dr Mikias Biazin, Prof Messele Negash, Dr Muluken Mekuyie, Dr Zebene Asfaw, Prof Fantaw Yimer, Dr Yirdaw Meride, Mr Ararsa Deresse, Mr Nega Challie, Mr Biruck Jangiso, Mr Bamlaku Ayenew and Mr Gebremedhin Ambaw for their inspiration and willingness to support my work. I would like to acknowledge Ms. Imelda Ingumba, Mr. Philbert Okello, and other colleagues from the ICRAF-SEI for their encouragement and facilitation throughout my time at ICRAF. My sincere gratitude goes to Ms Selam Abadir for her excellent driving support during the field data collection period in Doyogena district, Kembata Tembaro Zone, Southern Ethiopia.

My deepest gratitude goes to my wife Ms Ager Zelalem Temesgen, my late father, Mr Belay Mekonnen, my two sons, Yonas Abrham Belay and Dagim Abrham Belay, and the entire families, as this thesis would not have been possible without their great sacrifices. At the same time, I would like to thank my colleagues and mentors who I haven't mentioned your names, but you all contributed significantly to the success of this thesis.

I am also grateful to the financial support of the Swedish International Development Agency (SIDA) through the Stockholm Environment Institute (SEI) Regional Engagement Fund for Africa" and the Deutscher Akademischer Austauschdienst (DAAD) through World Agroforestry Center (ICRAF). I wish to express my sincere gratitude to the International Livestock Research Institute (ILRI) for supporting my fieldwork through a World Bank grant "Accelerating Impacts of CGIAR Climate Research for Africa (AICCRA)" ESA regional project (Grant No. D7540) signed between Alliance-Bioversity-CIAT and the International Development Association (IDA) and the AGNES-BAYER Sciences Foundation for assistance with field data collection. I am thankful to express my gratitude to the University of Nairobi in Kenya, the Center for Development Research (ZEF) at the University of Bonn, and the European Forest Institute's Bonn office in Germany and Hawassa University, Wondo Genet College of Forestry and Natural Resources in Ethiopia for their contributions to my research and overall support.

ABSTRACT

Climate change is a major concern for agriculture in East Africa, particularly in Ethiopia, with direct implications for smallholder farmers' incomes and food security. Despite the promotion of climate-smart agriculture (CSA) as a potential adaptation solution, there is a lack of rigorous evidence on its effectiveness in improving incomes and ensuring food security. This Thesis is aimed to examine the adoption of Climate Smart Agriculture (CSA) practices by smallholder farmers in southern Ethiopia and study used data from 385 randomly selected households and historical meteorological data for the years 1983 to 2016. A Heckman probit two-stage selection model was also applied to examine the factors influencing farmers' perceptions to climate change and their adaptation measures through adoption of CSA practices, which was supplemented by key informant interviews and focus group discussions. The propensity score matching approach with various types of matching algorithms was used to quantify the conditional effects of CSA intervention on income and food security. The results from the analysis of meteorological data showed that rainfall and temperature varied significantly across the study area. The survey findings indicated that a significant number of farmers (81.80%) observed a shift in the local climate. Specifically, 71.9% noted an increase in temperature, while 53.15% reported a decline in rainfall. Results also showed that farmers adaptation to climate change through adoption of CSA practices was influenced by level of education, family size, gender, landholding size, farming experience, access to climate information, social membership, livestock ownership, income, and extension services. The study also found that farmers' perceptions of climate change and variability were significantly influenced by age of the farmers, level of education, farming experience, and access to climate information. In comparison to the food consumption score, farmers that adopted CSA practices had a higher food consumption score of 43.70, whereas non-adopters had 36.40. Furthermore, 34.55%, 44.68%, and 20.77% of all interviewed farmers were found to have acceptable, borderline, or poor categories of food consumption status, respectively. The study concluded that effective extension services, accurate climate information, and policy support are required to promote and scale up the uptake of CSA practices the study area to improve farmers' adaptive capacity and food security and recommended that an enabling agricultural policy environment should be put in place to support the efforts of farmers to utilize CSA practices and technologies.

Table of Contents

PLAGIARISM STATEMENT ii

DEDICATION............ iii

ACKNOWLEDGMENT iv

ABSTRACT............ vi

LIST OF FIGURES xi

LIST OF TABLES xii

LIST OF ABBREVIATIONS xiii

CHAPTER ONE: INTRODUCTION............1

1.1. Background Information............1

1.2. Statement of the problem 5

1.3. Research questions............7

1.4. Objective of the study 7

1.5. Justification and significance of the study 7

1.5.1 Justification 7

1.5.2 Significance of the study............8

1.6. Scope and limitation of the study............9

1.6.1 Scope............9

1.6.2 Limitation............10

1.7. Structure of the Thesis 10

CHAPTER TWO: LITERATURE REVIEW............11

2.1. Introduction............11

2.2. Climate Change and Variability............11

2.2.1. Impact of climate Change on agriculture 14

2.2.2. Impact of climate change on farmers household income............17

2.2.3. The impacts of climate change on food security............18

2.3. Farmers' perceptions of climate change and the use of CSA practices as an adaptation strategy............19

2.4. Adoption of CSA practices 20

2.5. Impacts of CSA practices on farmers income and food security 22

2.6. Strengths and challenges of Climate Smart Agriculture 25

CHAPETR THREE: STUDY AREA, DATA AND METHODS 28
3.1. Introduction 28
3.2. Study area location and description 28
3.3. Biophysical Setting 30
3.3.1. Climate 30
3.3.2. Vegetation 30
3.3.3. Land use and resources 31
3.3.4. Physiography and Drainage 31
3.3.5. Water resources 32
3.3.6. Biophysical vulnerabilities 32
3.4. Socioeconomic Setting 33
3.4.1. Political and administrative context 33
3.4.2. National/regional/local Economic setting 33
3.4.3. Social setting 33
3.4.4. Health setting 34
3.4.5. Regulatory Framework 34
3.4.6. Socioeconomic vulnerabilities 34
3.5. Conceptual Framework 35
3.6. Methodology 39
3.6.1. Research design 39
3.6.2. Analysis of trends and variability of rainfall and temperature 40
3.6.2.1. Desktop studies 40
3.6.2.2. Fieldwork Studies 41
3.6.2.3. Data Analysis 41
3.6.3. Investigating farmers' knowledge of climate change and adoption of climate-smart farming practices for climate change adaptation 45
3.6.3.1. Desktop Studies 46
3.6.3.2. Fieldwork Studies 46
3.6.3.3. Data Analysis 49
3.6.4. Examining the impacts of CSA on household income and food security. 52
3.6.4.1. Desktop Studies 52

3.6.4.2.Fieldwork Studies 52
3.6.4.3.Data Analysis 53
CHAPTER FOUR: RESULTS AND DISCUSSION ON CLIMATE VARIABILITY AND TRENDS IN SOUTHERN ETHIOPIA 58
4.1. Introduction 58
4.2. Results obtained for Objective One 58
4.2.1. Rainfall Summary Statistics 58
4.2.2. Linear Trend Analysis of Annual and Seasonal Rainfall 59
4.2.3. Rainfall Variability 61
4.2.4. Trends of Drought 63
4.2.5. Temperature Trends 64
4.3. Discussion 65
4.4. Summary 67
CHAPTER FIVE: RESULTS AND DISCUSSION ON FARMERS' KNOWLEDGE OF CLIMATE CHANGE AND USE OF CLIMATE-SMART FARMING PRACTICES FOR ADAPTATION 69
5.1. Introduction 69
5.2. Results 69
5.2.1. Socio-demographic background 69
5.2.2. Farmers perceived impacts of climate change and variability 72
5.2.3. Farmers’ adoption of CSA Practices 74
5.2.4. Determinants of farmers' perceptions of climate change and adoption of CSA Practices .78
5.3. Discussion 80
5.4. Summary 88
CHAPTER SIX: RESULTS AND DISCUSSION ON THE IMPACT OF CLIMATE SMART AGRICULTURE (CSA) PRACTICES ON HOUSEHOLD INCOME AND FOOD SECURITY 89
6.1. Introduction 89
6.2. Results 89
6.2.1. Socioeconomic characteristics of CSA adopters and non-adopters 89
6.2.2. Estimation of propensity score and matching 93

6.2.3. Estimation of the average treatment effect of CSA adoptions 96
6.3. Discussion 97
6.4. Summary 100
CHAPTER SEVEN: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS 102
7.1. Synthesis 102
7.2. General Conclusion..105
7.3. Recommendation and policy implications 107
Reference 108
Appendixes...145

LIST OF FIGURES

Figure 3.1 Map of the study area (author's own work, 2022) 29
Figure 3.2: Conceptual framework of the study 38
Figure 4.1: Seasonal rainfall trends over the observed period for 1983-2016..............................60
Figure 4.2: Annual trend of rainfall between 1983-2016 61
Figure 4.3: Standardized rainfall anomalies for monthly means (1983-2016).............................61
Figure 4.4: Standard annual rainfall anomalies of the study area (1983-2016)............................62
Figure 4.5: Standard Precipitation Index (SPI) for Annual rainfall series (1984-2016)................63
Figure 4.6: Standard precipitation index (SPI) result for monthly time scales in the study area ..64
Figure 4.7: Temperature trends for maximum, minimum and mean temperature in the study area (1983-2016)..65
Figure 5.1. Channels of climate information for farmers in lemisutischo and begedamo............74
Figure 5.2 Farmers' adoptions of different climate-smart agriculture practices in the study sites76
Figure 5.3 Constraints of climate change adaptation measures...78
Figure 6.1: Selected farm management practices in farmers' farm plot.......................................91
Figure 6.2: Farmers' sources of income in the study region 92
Figure: 6.3 Different categories of farmers' food consumption score..93
Figure 6.4: Propensity score distribution and common support region for propensity score estimation:(a) treated and untreated propensity score; (b) propensity score in common support region. 95

LIST OF TABLES

Table 3.1: The name, altitude, coordinates, and years of the selected meteorological stations ... 41
Table 3.2. Standard Precipitation indices and their interpretation 45
Table 4.1: Summary statistics and MK trend test result (1983-2016) 59
Table 4.2: Precipitation changes on an annual and seasonal basis (1983-2016) 60
Table 4.3: Years of the different PCI class in the study area (1984-2016).................................. 62
Table 5.1. Farmers' awareness and perceptions of climate change and shocks 70
Table 5.2. Smallholder farmers' perceptions of the impact of climate change-related events in Lemisuticho and Begedamo Kebele 73
Table 5.3: Summary of the benefits of different CSA practices 75
Table 5.4. Summary of aggregate crop yield production estimate 77
Table 5.5. Results of the Heckman probit selection model 79
Table 6.1. Summary of the variables included in the model 90
Table 6. 2. The estimated results of the logit specification of the propensity scores 94
Table 6.3. The average impact of CSA adoption on household income and food security.......... 96

LIST OF ABBREVIATIONS

ADLI	Agriculture Development Led Industrialization
AGNES-BAYER	African Group of Negotiators Experts Support Bayer Foundation
AICCRA	Accelerating Impacts of CGIAR Climate Research for Africa
ATA	Agricultural transformation Agency
ATE	Average Treatment Effect
ATT	Average Treatment Effect on Treated
ATU	Average Treatment Effect on Untreated
AUC	Africa Union Commission
CC	Climate Change
CCA	Climate Change Adaptation
CCAFS	Climate Change, Agriculture and Food Security
CGIAR	Consultative Group for International Agricultural Research
CHIRPS	Climate Hazards Group Infrared Precipitation with Station data
CIAT	Centro Internacional de Agricultura Tropical
CM	Caliper Matching
CRGE	Climate Resilient Green Economy
CSA	Climate Smart Agriculture
CV	Coefficient of Variation
DAAD	Deutscher Akademischer Austauschdienst
ENSO	El-Niño Southern Oscillation
ESA	East and Southern Africa
ESR	Endogenous Switching Regression
ETB	Ethiopian Birr
FAO	Food and Agriculture Organization
FCS	Food Consumption Score
FDRE	Federal Democratic Republic of Ethiopia
FGD	Focus Group Discussion
FTC	Farm Training Center
GDP	Gross Domestic Product
GHGs	Greenhouse Gases
GPCC	Global Precipitation Climatology Center
HDDS	Household Dietary Diversity Scores
HFCS	Household Food Consumption Score
ICRAF	World Agroforestry Centre
ILRI	International Livestock Research Institute

INFORM	Index For Risk Management
IOD	Indian Ocean Dipole
IPCC	Inter-Governmental Panel on Climate Change
ITCZ	Inter Tropical Convergent Zone
KBM	Kernel Based Matching
KII	Key Informant Interview
MK	Mann Kendall
MNL	Multi-Nomial Logit
MoFed	Ministry of Finance and development
NARI	National Agricultural Research Institute
NGOs	Non-Government Organizations
NMA	National Meteorological Agency
NNM	Nearest Neighbor Matching
PCI	Precipitation Concentration Index
PSM	Propensity Score Matching
RISING	Research in Sustainability Intensification for the Next Generation
RM	Radius Matching
SAI	Standard Anomaly Index
SD	Standard Deviation
SDGs	United Nations' Sustainable Development Goals
SEI	Stockholm Environment Institute
SIDA	The Swedish International Development Cooperation Agency
SNNPR	Southern Nations, Nationalities, and Peoples Region
SPI	Standard Precipitation Index
SRAI	Standardize Rainfall Anomaly Index
SSA	Sub-Saharan Africa
SSTs	Sea Surface Temperatures
STATA	Statistical Software Package
SWC	Soil and Water Conservation
TLU	Tropical Livestock Unit
TPB	The theory of planned behavior
UNFCCC	United Nation Framework Convention on Climate Change
USD	US Dollar
WFP-VAM	World Food Programme-Vulnerability Analysis and Mapping
WMO	World Meteorological Organization
ZEF	Zentrum für Entwicklungsforschung

CHAPTER ONE: INTRODUCTION

This chapter provides an overview of climate Change (CC) and variability, adaptation options based on climate smart agriculture (CSA) practices, the statement of the problem, the study objectives, and its significance.

1.1. Background Information

Climate change threatens global agriculture, food security, and the livelihoods of billions of global populations (Field, 2014; Abidoye *et al*., 2015; Reidmiller *et al*., 2018; IPCC, 2022). Previous research indicate that increased temperatures will probably have adverse effect on farming system (Aggarwal *et al*., 2009; Lobell *et al*., 2012), precipitation change (Mall *et al*., 2006; Prasanna, 2014), and shifts in the intensity and incidence of droughts and floods (Brida and Owiyo, 2013; Singh *et al*., 2013). The FAO (2016) indicates that between 2004 and 2014, the estimated costs and risks related to the global impacts of climate change on agricultural system reached $100 billion USD. According to Njeru *et al.* (2016), approximately 2.5 billion people worldwide make their livelihoods from the agricultural sector. However, 690 million people worldwide are struggling with famine (Zougmoré *et al.,* 2021).

Climate change has a detrimental effect on the security of food and crop productivity in Eastern African countries (Porter *et al*., 2014; Salahuddin *et al*., 2020). Recent literature suggests local farmers' resilience to the impact of climate change is associated to various adaptation strategies (FAO, 2021; Mekonnen *et al.*, 2021; Jellason *et al.*, 2022). Applying climate change adaptation methods to agriculture could help with several issues, including poverty alleviation, food, and nutrition insecurity, and safeguarding human welfare under changing climate. This is particularly relevant for low-income nations in ‘Sub-Saharan Africa (SSA’) such as Ethiopia. This is because the adverse effects of climate change on agricultural and food require adoption of feasible adaptation efforts to reduce these impacts and enhance productivity (FAO, 2016).

The FAO (2009) introduced the concept of CSA for the first time. Climate smart agriculture practice has been promoted to increase farmers' resilience, agricultural productivity, and food security (FAO, 2013). Three major pillars support the adoption of CSA approaches. The first pillar is aimed to achieve sustainable growth in agricultural productivity while also fostering improvement in farm incomes, food security, and the overall development of rural communities. Its second goal is to strengthen and adapt food systems to climate change. Finally, it seeks to reduce GHGs emissions from agriculture wherever possible (FAO, 2013).

Climate change adaptation measures are classified as "climate-smart" based on the influences on the above- mentioned three pillars, and agricultural practices that meet those goals are referred to as "climate-smart." (FAO, 2010; FAO, 2013). Climate smart agriculture encompasses a range of micro-level conservation measures that aim to support farmers in response to climate change and its effects. These include the application of agroforestry techniques, the adoption of improved crop varieties, enhanced livestock breeding, and soil and water conservation (SWC) (Bazzana *et al*., 2022). More broadly, CSA is "an approach for transforming and reorienting agricultural development under the new realities of climate change" (Lipper *et al*., 2014). The goal of CSA practices is to develop internationally applicable concepts for maintaining agriculture for food security in the face of climate change. The 'Food and Agriculture Organization of the United Nations' and other multilateral organizations rely on these principles as the basis for their policy recommendations and support. The development of the CSA approach was motivated by the need to get a more holistic understanding of agriculture's contribution to assuring food security and its capacity meet the adaptation and mitigation issues in the context of global climate policy (Lipper *et al*., 2017).

Different agriculture practices provide different "climate-smart" benefits (FAO, 2013). Reppin *et al*. (2019) conducted a case study in the western part of Kenya and found that trees in an agroforestry system provide household firewood, lumber for generating income, and carbon sequestration estimated 4.07 Mg C/ha. Similar improvements in agriculture productivity, income, and food security indicators were measured in Tanzania and Zimbabwe by diversifying cropping systems (Makate *et al*., 2016; Kimaro *et al*., 2019).

Implementation of crop diversification also enhances soil fertility, reduces pest and disease pressures, and enhances resilience and biodiversity on farms (Kurgat *et al.*, 2020). In a different study, the application of agroforestry and conservation agriculture improved maize yield, strengthened adaptation to climate change in Tanzania (Kimaro *et al*., 2016). CSA practices increased agricultural production by 22% for north-west Ethiopian farmers between 2015 and 2017(Asrat and Simane, 2017). Farmers that grow both perennial and annual crops are more likely to boost agricultural productivity, better their livelihoods, and create more sustainable agroecosystems. Perennial crops, which require fewer expensive inputs and incur lower ploughing and planting costs (Crews *et al.*, 2018; Fadina and Barjolle, 2018; Kogo *et al.*, 2022).

According to recent studies conducted in Eastern African countries, the region's agriculture sector experiences low production and food insecurity due to the presence of unpredictable rainfall patterns and temperature fluctuations (Austin *et al*., 2020; Ojara *et al*., 2021; Kogo *et al*., 2021; Stuch *et al*., 2021; Fusco, 2022). According to Kogo *et al*. (2021), Kenya's agricultural production is significantly affected by current climate change, and this is projected to continue. According to Ojara *et al*. (2021), Tanzania's maize production is likely to suffer from severe climate change events and Austin *et al*. (2020) note climate change is worsening Rwandan farming system; it is critical to comprehend how agricultural adaptation actions can reduce the severity of climate change effects (Ogada *et al*., 2020).

Although it has been shown that CSA is a viable approach for mitigating climate change risks in Ethiopia, smallholder farmers have different challenges when deciding whether to adopt adaptation strategies (CIAT, 2017; Teklu *et al.*, 2022). Various factors, such as restricted credit availability, insufficient education and extension programs, and infrequent and weak agricultural extension support, have been identified in the literature as major barriers to farmers' ability to adapt, these factors are hence reducing agriculture production and food systems in rural areas (Khonje *et al*, 2018; Ojo and Baiyegunhi, 2020). The impact of climate change in Ethiopia has reduced agricultural production, caused food insecurity (Hilemelekot *et al*., 2021), displaced people (Solomon *et al.,* 2018), increased poverty (Onyutha, 2019; Seife, 2021), and exacerbated conflicts (Van Weezel, 2019). The agricultural sector in Ethiopia contributes 52% of the GDP, 80% of employment, and 80.2% of foreign exchange profits (Belay *et al.,* 2021; Zerssa *et al.*, 2021) and hence the primary risk that CC poses to the economic gains of the federal government.

The country's agricultural sector is characterized by smallholder mixed crops and low-level livestock production, as well as inadequate extension services (Tessema and Simane, 2021). These factors impede the ability of small-scale producers to respond to climate change (Jha and Gupta, 2021). Although the magnitudes of these effects are not well understood, recent studies in Ethiopia have shown that climate change has long-term, adverse effects on farmers' livelihoods (Araro *et al.,* 2020; Koch *et al.*,2022). According to Talanow *et al.* (2021), there is inadequate evidence as to whether smallholder farmers' understanding, and perception of climate change affect their level of adoption measures.

There is a lack of empirical data on farmers' perceptions, behaviours, and knowledge about climate change adaptation strategies. Research conducted in southern Ethiopia has indicated that unpredictable precipitation patterns threaten food security and crop yields (Wodaje *et al*., 2016; Philip *et al*., 2018; Zewdu *et al.,* 2020). Smallholder farmers may be more responsive to adopting CSA measures to mitigate climate change if their knowledge and perceptions are considered during the CSA adoption process (Jellason *et al.,* 2019). Adaptation refers to the local response to climate change and its impacts. It is critical to address the knowledge gap among smallholder farmers on climate related effects (Ricart *et al.,* 2022). Previous studies report that CSA practices improve farming's resilience to climate change (Aryal *et al.,* 2018; Wake *et al.,* 2019; Ogada *et al*., 2020; Mugabe, 2020).

Ethiopia has historically struggled with food insecurity and climate change; to develop measures for adaptation and mitigation, the ministry of agricultural in Ethiopia announced the policy document named Climate Resilient Green Economy (*CRGE*) program in 2011 (CIAT, 2017; FDRE, 2019). Among the key initiatives include different land management approaches such as agroforestry, area closures, improved crop-livestock production, soil, and water conservation using biological methods (FDRE, 2019; Paul and Weinthal, 2019). Despite global attention and investment in CSA, there is few studies on the effects of CSA measures on household income and food security in Ethiopia (Zerssa *et al.*, 2021). Farmers who adopt CSA practices may benefit from adaptation and mitigation to a changing climate. This is shown by studies conducted in East and South African countries, which indicates that implementing CSA practices can lead to improve revenue and food production (Wekesa *et al.,* 2018; Makate *et al*., 2019; Ogada *et al*., 2020; Mugabe, 2020; Mujeyi *et al*., 2021).

For the past decade, locally adapted CSA practices have been introduced and promoted in the Doyogena district of southern Ethiopia. However, there is a limitation of broad understanding and documentation regarding the effect of CSA interventions on household revenue and food safety. Therefore, further studies are needed to determine how farmers' awareness and understanding influences the implementation of CSA measures on food security and income. This study examines how smallholder farmers in Southern Ethiopia are using CSA considering the changing climate. The estimation of the socioeconomic impacts of CSA activities aims to fill the existing knowledge gap and highlights the importance of promoting and expanding locally applicable CSA options.

1.2. Statement of the problem

Ethiopia is highly vulnerable to climate change and variability due to its reliance on rain-fed agriculture and natural resources, as well as its low capacity to adapt to projected changes (Philip *et al.*, 2018; World Bank, 2021). Historically, Ethiopia has encountered climatic change and variability, resulting in food insecurity (Lewis, 2017; Girma *et al.*, 2023). Smallholder farming in the Southern Ethiopia depends on rainfall and is extremely vulnerable to the impact of climate change. These impacts include increased variability in the timing and duration of rainfall, heavy rainfall events, strong winds, rising temperatures, as well as the incident of sudden floods and extended droughts. The practices of conventional farming such as frequent ploughing and removal and burning of crop residues in Ethiopia has resulted in the degradation of soil quality, leading to a decline in crop productivity.

Climate extremes, combined with conventional farming practices and the area's high slope topography, create land degradation and soil fertility loss, which affects agricultural production and leads to a shortage of cattle feed, as well as food insecurity and reductions in household income (Bonilla *et al*., 2020). Climate change has an adverse effect on food security, and it is an important cause of food poverty due to its direct effects on yields as well as its indirect effects on diseases, pests, and water availability and quality (FAO, 2016). Some smallholder farmers are adopting CSA as a potential solution to mitigate the negative effects of climate change (CIAT, 2017).

The CSA approach is considered a more sustainable alternative to conventional farming practices as it improves the agriculture systems' ability to withstand the negative impacts of climate change, reduces GHG emissions, and increases agricultural productivity and profitability (FAO, 2013; Engel and Muller, 2016). Empirical findings from some Eastern and Southern African countries shows that the implementation of CSA techniques by farmers enhances their capacity to adapt to climate change measures (Wekesa *et al.* (2018), Makate *et al.* (2019), Ogada *et al.* (2020), Mugabe (2020), and Mujeyi *et al.* (2021). In the study area, different climate-smart practices are being developed, tested, and prompted through partnerships with the government, non-governmental organizations, and local communities. Despite the increasing recognition of CSA practices and their potential to improve agriculture production, limited studies have measured the effects of CSA on revenue and food security in different parts of Eastern Africa countries (Ogada *et al*., 2020; Mugabe, 2020; Bazzana *et al*., 2022). There is currently a limited level of evidence and understanding of climate change and the impacts of CSA measures on food security and income in the study site.

Limited studies have attempted to analyze climate trends and variability in the study region, and the findings from these studies have failed to establish consistent trends. The causes for the conflicting results might vary and include limitations in the quantity and quality of data available, as well as methodological differences in the analytical. For example, studies conducted in North and Southwestern Ethiopia have shown that there is no significant trend in annual and seasonal rainfall patterns (Girma *et al.,* 2016; Gebremicael *et al.,* 2017). Other studies in Ethiopia indicate increasing temperatures and falling rainfall patterns (Mekasha *et al*., 2014; Weldegebriel and Prowse, 2017; Asfaw *et al*., 2018). Understanding local climate trends and farm household socioeconomic behavior are necessary to take up and strengthen adaptation measures (Wouterse *et al.,* 2022). Farmers' commitment to use CSA adaptation measures is determined by their understanding and perception of climate change and variability. However, farmers' responses to adaptation decisions may be driven by internal and external factors which could constrain participation in the CSA-adoption process (Below *et al*., 2015). In this context, it is critical to investigate farmers' knowledge of climate change, and perceptions toward adaptation measures. Therefore, this study investigates the adoption of CSA practices among smallholder farmers and its implication for climate change adaptation in Southern Ethiopia.

1.3. Research questions

These are the study's research questions.

i. What temporal variability and trends in temperature and rainfall patterns was observed in the study area from 1983-2016?
ii. How do farmers' perceptions and knowledge of climate change influence their adoption of climate smart agriculture practices for climate change adaptation measures?
iii. What are the main effects of climate smart agriculture practices on household income and food security?

1.4. Objective of the study

The main objective of this study is to investigate into the adoption of CSA practices among smallholder farmers and its implication on climate change adaptation in Southern Ethiopia. The specific objectives of the study are outlined below:

a) To analyse climate variability and trends from 1983 to 2016 in the study area
b) Assess farmers' knowledge of climate change and the use of climate-smart agriculture practices for climate change adaptation; and
c) To examine the effects of climate smart agriculture practices on food security and household income.

1.5. Justification and significance of the study

The significance and justification for the study are as follows:

1.5.1 Justification

Farmers in Ethiopia face a variety of climate-related threats, such as rainfall variability, rising temperatures, decreasing water resources, a decline in agricultural production, land degradation, soil erosion, floods, and droughts (Hilemelekot *et al*., 2021). Smallholder farmers have adopted improved farming systems as an option to conventional practices to mitigate the adverse effects of climate change.

This approach increases agricultural output and income while increasing resilience to climate change (FAO 2013, Engel and Muller, 2016). Understanding the adaptation measures employed by local farmers in the study site, regardless of whether they are considered "climate smart," is critical in dealing with the adverse impact of climate change on agriculture. Assessing the extent of this impact and putting CSA adoption strategies into practice are crucial steps in reducing the negative effects of climate change. The size of the farm plot, the weather, and other environmental factors, as well as ecological, cultural, geographic, political, institutional, and socioeconomic considerations, all influence how farmers respond to climate change challenges (Wouterse *et al.*, 2022).

Understanding the complexity of climate change adaptation strategies, as well as exploring the factors that influence adaptation measures, can greatly influence policymakers and priorities (Carlos *et al*., 2020). The successful adoption of CSA practice and technologies by farmers relies heavily on robust policy support. This support is crucial in motivating farmers to embrace improved agricultural practices and strengthen their ability to adapt at the household level.

1.5.2 Significance of the study

The government of Ethiopia has prioritized agriculture and implemented a variety of measures to increase productivity (FAO, 2016) including Climate Resilient Green Economy (Aweke, 2017). The country's strong reliance on agriculture is an issue of concern, given its vulnerability to climate variability and change (Addisu *et al.,* 2019). Ethiopia, with 120 million people, is the second biggest population in Africa (Argaw, 2023). The Ethiopian development agenda is nested in Africa Union’s Agenda 2063, which is adaptation to climate change and increasing adaptation capacity through suitable agricultural investments (Africa Union Commission, 2015) and the ‘United Nations' Sustainable Development Goals (SDGs)’ which calls for sustainable agriculture, food security, and poverty reduction by 2030 (Omilola and Robele, 2017). Current CSA practices and technology contribute particularly to SDGs 1 (end poverty), SDGs 2 (end hunger and promote sustainable agriculture), SDGs 3 (health and wellbeing) SDGs 13 (fight climate change), and SDGs 15 (life on land).

The study contributes to the current body of knowledge by providing important baseline data for future research and policy intervention in Ethiopia, which was launched a comprehensive climate change policy document in 2011(CRGE, 2011; Paul and Weinthal, 2019). Specifically, the findings of the research do support the current CSA policy intervention and address institutional and external factors that impede smallholder farmers from adopting CSA practices. Additionally, the study contributes to evidence showing how farmers' knowledge of and perception of climate change influences their implementation of CSA measures, which improves the likelihood of smallholder farmers. The findings of this research can be used to shape agricultural policies, programs, and initiatives in the country, adding to the current body of knowledge by providing critical basic information for future CSA studies and policy action.

1.6. Scope and limitation of the study

The scope and limitation of the study are as follows:

1.6.1 Scope

Food security and agricultural productivity are seriously threatened by climate change, and CSA is crucial to reducing the negative impacts. This study focuses on smallholder farmers' adoptions of CSA under changing climate in Doyogena district, Southern Ethiopia, where CSA interventions have been promoted and employed with the support of governmental and NGOs. The study investigates observed trends and variability of climate in the research site, farmers' awareness of climate change and variability, implementation of CSA practices as an adaptation strategy, as well as its effects on household income and food consumption in 2020/2021. The study analyzed observed two key parameters of climate trends in the study area using 34 years (1983–2016) of historical meteorological data and cross-sectional survey data from 385 randomly selected survey participants.

1.6.2 Limitation

The climatic trend and variability analysis was conducted by integrating rainfall and temperature data from local weather stations in the study area. This method made use of the combined data from six stations (Doyogena, Angacha, Durame, Alaba Kulito, Hossana and Fonko) provides more comprehensive understanding on the regional climate. As each station may have a unique analysis result, more research is needed to account for these limitations and provide station-based analysis and provide recommendations. The study depends on cross-sectional household data at the farm level, which hinders the ability to track the development of the CSA intervention over time. Due to the spillover effects of the intervention and unobserved heterogeneity, this may have an impact on the estimation results.

This study focused on the aggregate effect of CSA practices on farmer income and food security. However, each CSA practice may have a unique impact on household well-being, and a dedicated study for each adoption measure is necessary to provide specific recommendations on the relevant CSA measures. The COVID-19 pandemic and ethnic-based conflicts were the major obstacles that impeded the in-person data collection process.

1.7. Structure of the Thesis

This doctoral thesis is structured into seven chapters. Following on from the earlier chapter one, the introductory section, the second chapter gives a review of the literature, and the third chapter covers the study area and the detailed methods used. The climate variability, trends and results are presented and discussed in the fourth chapter; the fifth chapter discusses how farmers' knowledge and perceptions of climate change influence CSA adoption; and the sixth chapter discusses the effects of CSA measures on household income and food security. In the final chapter, the conclusions from the earlier chapters are synthesized and appropriate recommendations drawn.

CHAPTER TWO: LITERATURE REVIEW

2.1. Introduction

This section presents literature review on historical and contemporary trends in climate change and variability, as well as how awareness of such trends might help smallholder farmers implement adaptation plans into practices. Afterwards, reviewed the effects of climate change on agriculture and assessed how implementing CSA practices could potentially improve household income and food security.

2.2. Climate Change and Variability

Climate change and variability are still a global issue that threatens all sectors of economic development (IPCC, 2014). The 'United Nations Framework Convention on Climate Change (UNFCCC)' recognizes that human activity is the primary driver of greenhouse gas emissions. The effects of climate change are becoming more and more apparent in the twenty-first century, affecting every country (Reidmiller *et al.*, 2018; IPCC, 2022). The impacts of climate change and related risks including flooding, land-use changes, poverty, inequalities, social exclusion, food insecurity, extended drought and associated vulnerability conditions have led to the substantial decline of developing countries economy (IPCC, 2014). The 2022 IPCC report states that global climate system has changed and from now only the most extreme reductions in carbon emissions will help prevent an environmental catastrophe as the world is expected to approach the 1.5^{o}C level over the next two decades.

Both developed and developing countries require substantial actions on reducing global greenhouse gas emissions through strong mitigation and adaptation actions (Anderson, 2015; Pörtner *et al.*,2022). Climate change has a large impact on African countries, whose main economic developments are largely dependent on climate-sensitive sectors with limited adaptation capacity (Anderson *et al.*, 2010; Mesfin *et al.*, 2020). Africa accounts for 7% of global carbon emissions, and global warming is already having an impact on its hydroclimate, biodiversity, wildfire dynamics, and societal and economic growth (Al-Zu'bi *et al.*,2022).

The adverse effects of climate change have led to an increase in the amount of land degradation, which in turn reduces productivity of agricultural and threatens food security in SSA, particularly in Eastern Africa, including Ethiopia (Stuch *et al*., 2021). According to recent research, the main factors causing rainfall variability in Eastern Africa are ‘El Niño Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD)’ (Saji *et al*.,1999; Tierney *et al.*, 2013; Urgessa, 2013; Wodaje *et al.*, 2016; Minda *et al.*,2018; Dubache *et al.*, 2019). These factors have a substantial impact on crop production and vegetation, which in turn affects food and social security.

Ethiopia is extremely susceptible to the effects of climate change since it has a low potential for adaptation (Mekonnen *et al.*, 2021). The temperature level in Ethiopia has risen by 1°C starting since 1960, or 0.25°C every ten years (World Bank, 2021). Increases are especially visible between July and September. From 1960 to 2003, there was an increasing trend and frequency of "hot nights" by approximately 37.5%, alongside a 20% increase the incidence of "hot days" per annum (World Bank, 2021). The central and highland regions of the country have been impacted by higher rates of warming. As a result of the observed temperature increase, evapotranspiration and soil moisture levels have both increased. The precipitation patterns in Ethiopia have been challenging to measure over an extended period due to their high unpredictability. Nevertheless, throughout the previous four decades, there has been an overall decrease in precipitation, with significant annual variability (World Bank, 2021).

Some regions are predicted to have less rain, despite Ethiopia's extremely unpredictable precipitation patterns. For example, the south-central part of the country has had a 20% decrease in rainfall since 1960. According to 2021 World Bank report, average temperatures are expected to rise significantly in Ethiopia. Assuming a high-emission scenario, the mean monthly temperature fluctuations are predicted to increase by 1.8°C by the 2050s and 3.7°C by the 21st century. The projections indicate that the incidence of "hot day" is probably going to rise considerably over time. Specifically, it is estimated that by the 2060s, "hot days" will occur on 19 - 40% of days, and by the 2090s, this frequency is expected to rise to 26 - 69% of days. According to projections, the months of July, August, and September are expected to experience the highest rates of increase. Based on the World Bank's report in 2021, temperatures in Ethiopia are projected to increase in the coming decades.

Ethiopia has a significant degree of inter-annual variability, and future estimates of Ethiopia's precipitation patterns are highly uncertain. The expected future patterns of rainfall in the southern and central regions will be reduced by 20% during the spring and summer seasons. The warming trends projected for the entire country are expected to exacerbate observed rainfall decreases, resulting in severe water stress. Climate change is having a profound impact on social, economic, political, and environmental systems within the country (IPCC, 2021). Ethiopia is severely affected by extreme weather changes, and this intensifies low productivity of farming system and food insecurity (Amare and Simane, 2017). The average national temperature of Ethiopia has increased by 0.37^0C (Gebrechorkos *et al.*, 2019). A decreasing rainfall trend has been observed in Ethiopia since the 1990s (Abebe, 2017; Abebe, 2008) and this has considerably affected the farming system in the country. The ENSO event coupled with the anthropogenic activities has greatly contributed to climate change (Diro *et al.*, 2012; Rowell *et al.*, 2015).

Recent studies conducted in Africa of Eastern region particularly in Ethiopia, on multi-decadal variability of climate reveals mixed results. Some of the studies show declining trends of annual rainfall while others indicate an increasing pattern of rainfall (Tierney *et al.*, 2013; Rowell *et al.*,2015; Asfaw *et al.*, 2018; Philip *et al.*, 2018; Benti and Abara, 2019; Shawul and Chakma, 2020). The causes for the conflicting results might vary and include limitations in the quantity and quality of data available, as well as methodological differences in the analytical.

According to Cheung et al. (2008), trend assessment of rainfall for over 134 sites in 13 watersheds, the Southwestern and Central Rift Valleys of Ethiopia experienced a substantial decrease in *Kiremt* (June-September) rainfall trends. The central highlands and northwestern part of Ethiopia had recorded decreasing precipitation distribution during the cropping season (Asfaw *et al.*, 2018). The study used pixel-based Mann-Kendall trend analysis and Vegetation Condition Index (VCI) and the findings show significant countrywide droughts were recorded during El Niños in the 2009–2005 period. In Ethiopia, El Niño creates drier conditions which affects the planting season June to September (Gleixner *et al.*, 2017). During the 2015 El Niño, farmers had to change their planting season due to below-average rainfall during the "Kiremt and Belg" rainy season (Singh *et al.*, 2016; Philip *et al.*, 2018).

Ethiopia in general and southern Ethiopia in particular have two distinct rainy seasons: the primary one, which lasts from June to September, and the secondary one, which runs from February to May. Some southern parts of the country, such sa Borena, also benefit from the little rainfall that falls between October and December. Ethiopia's national meteorological agency (NMA) report states, the average yearly national rainfall pattern remained constant between 1951 and 2006, but rainfall patterns in *Kiremt* and *Belg* have been highly variable (NMA, 2007), while Fazzini *et al.* (2015) report that annual and spring rainfall in Ethiopia has been decreasing over the last thirty to fifty years. This contradiction may happen due to the data quality or different data analysis approach.

According to Wodaje *et al.* (2016), the Southern part of Ethiopia experienced significant spatial rainfall variability. Rainfall variability reduces the soil water availability to crops, resulting in reduced agricultural yield. Particularly, annual, and seasonal rainfall information is vital to overcome the socioeconomic challenges for farmers who depend on rainfall (Philip *et al.,* 2018; Zewdu *et al.,* 2020; Bedane *et al*.,2022). Analyzing rainfall trends and variability is essential for accurately predicting climate extremes and for implementing the necessary mitigation and adaptation strategies (Field, 2014).

2.2.1. Impact of climate Change on agriculture

Climate change has substantial consequences on agricultural systems. Temperature variations and precipitation have a major impact on crop production, quality and availability of soil and water. Droughts and floods are examples of severe weather events that may severely damage agricultural products and production of food. In addition, climate change has the possibility to increase the occurrence of pests and diseases, posing a greater threat to crops. This has a significant implication on food security and the well-being of rural communities. According to the 'IPCC Working Group II's Fifth Assessment Report', the greatest threat to the productivity of agriculture around the world is climate change and related impacts (Edenhofer, 2015). According to FAO (2021), climate change affects agriculture in several ways, including altered rainfall patterns, average temperatures as well as adverse weather conditions like floods and droughts, altered diseases and pests, altered carbon dioxide levels, altered food quality, and altered growing seasons.

Hoffmann (2013) indicated that during extreme weather events, crop yield has a strong correlation with temperature change and duration of warm or cold waves and varies based on plant maturation stages. Praveen and Sharma (2019) indicate that variation in rainfall patterns may exacerbate water scarcity and associated drought problems for crops, as well as changes in irrigation planning, all of which will reduce rainfall predictability for farmers and their respective adaptation planning.

Climate change is already reducing rice, maize, wheat, potatoes, and vegetable products on a global scale, and it will continue to do so severely by the year 2050 (Praveen and Sharma, 2019). Climate change is a major concern in all industries, including livestock, as it affects the quality and quantity of feed supply (Hoffmann, 2013). Recent reports indicate that climate change has already produced negative consequences on African agriculture and food security (Njeru *et al.,* 2016; von Braun, 2020). Recent studies show climate change is expected to cause a significant challenge to Africa's mixed crop-livestock farming practices (Thornton and Herrero, 2015; Antwi-Agyei *et al.,* 2021). Atwoli *et al*. (2022) indicate that in Africa, climate change associated risks include flooding, drought, and heat waves; these risks are reducing food production and decreasing labor productivity.

Atwoli *et al. (2022)* add that extreme weather affects water and food supplies, causing food insecurity and hunger, which affects 17 million people in Africa each year; malnutrition has increased by nearly 50% since 2012. Smallholder farmers, with their strong focus on climate-sensitive agriculture, face significant challenges because of climate change and its adverse impacts. These challenges can exacerbate issues such as unemployment, poverty, and hunger (Jiri *et al.,* 2018; Etana *et al.,* 2020; von Braun, 2020). Climate change and related impacts reduce agricultural crop yields and livestock production (Alewoye *et al.,* 2020; Pedersen *et al.,* 2021; Tsegaye *et al.*, 2017; Archer *et al.*, 2021). Climate change is severely impacting agriculture in Kenya (Kogo *et al*., 2021), in Tanzania (Ojara *et al*., 2021), Ghana (Austin *et al.,* 2020), Rwanda (Obeng *et al.*, 2013), and Ethiopia (Hilemelekot *et al.*, 2021). Ethiopia is specifically exposed to climate change in the areas of water, agriculture, infrastructure, forestry, and public health; its consequences are already seen across the country (World Bank, 2021). The impact of climate change and severe weather conditions in Ethiopia can be seen in various sectors. Agricultural production is significantly reduced, leading to food insecurity (Hilemelekot *et al*., 2021).

Additionally, these conditions contribute to displacement of people (Solomon *et al*., 2018), exacerbating poverty levels (Onyutha, 2019; Seife, 2021). Furthermore, the increased frequency of conflicts can be attributed to these climate-related challenges (Van Weezel, 2019). With 52% of the GDP and 80% of all jobs coming from the agricultural sector, Ethiopia's economy is based mostly on the agriculture sector. It also produces 80.2% of the foreign exchange profits, which makes it the main source livelihood (Deressa *et al*., 2011; Belay *et al.*, 2021).

The agricultural sector in Ethiopia is characterized by small-scale mixed crops and low-level livestock productivity, along with inadequate extension services (Tessema *et al.*, 2021). The primary causes for low productivity of the agriculture sector in Ethiopia include traditional agricultural practices, severe soil erosion caused by deforestation, overgrazing and poor institutional services (e.g., extension, credit services, and marketing), and extremes in the weather, including drought and flooding (Deressa *et al.*, 2011; Etana *et al*., 2020; Tesfahunegn *et al.,* 2021). The ability of farmers to adjust to climate change is negatively impacted by these factors (Jha et al., 2021).

Enhancing farmers' understanding of climate change and implementing adaptation strategies could mitigate the negative impacts of the event, boost the incomes of small-scale farmers, and improve food security (Talanow *et al.*, 2021; Ogundeji *et al.*, 2022). The agricultural sector in Ethiopia is severely affected by adverse weather conditions including extended flood and drought conditions (Feyissa *et al.*, 2018; Gemeda *et al.*, 2021; Wordofa *et al.*, 2021). For instance, Arndt *et al.* (2011) report that between 1991 and 2010, the country's economic performance decreased by 9% because of climate-related effects. Furthermore, Zewdu *et al.* (2020) projected that the national GDP will fall from 6% to 32.5% by 2030-2050, but Mideksa (2010) and CIAT (2017) predict that 8-10% of the GDP will be reduced from the planned objective in 2050.

According to Gemeda *et al.* (2021), variations in precipitation, including unpredictable rainfall patterns have a significant effect on crop yield in Ethiopia. Moreover, temperature variability has facilitated the growth and survival of pathogens throughout their lifecycle, thereby creating a conducive environment for pests and diseases (Ebi *et al.,* 2019). Furthermore, Ethiopia will continue to experience extreme floods and droughts in terms of their spatial extent and coverage.

Studies show that national crop production for all main crop species is expected to decline by 2050 it is expected teff production will decline by 25.4%, maize 21.8%, sorghum 25.2%, barley 30%, and wheat 25.5%, pulse 25.2%, oil seed 12.0%, vegetable 22.7%, and fruit 26.8% (Solomon *et al*., 2021; Mase *et al*., 2017; Tegegne *et al*., 2021).

2.2.2. Impact of climate change on farmers household income

The influence of climate change and variability on rural income is important, particularly when it is reliant on rain-fed agriculture that employs inefficient agricultural technology. There is an understanding that Climate change and weather variations negatively affect household welfare given that the farming system is among the vulnerable sector to climate change and related impacts (Auci and Coromaldi, 2018). Climate change impacts on household income will vary depending on the type of agroecology and crop systems in place. For example, farmers in rural environments that are prone to flooding and drought will be most affected (Altieri *et al.,* 2015). Perennial and diverse cropping systems are important for long-term food security, especially since weather patterns are becoming more unpredictable (Leisner, 2020; Sanford *et al.,* 2021).

In addition, smallholder farmers are greatly affected by climate change due to their dependence on rainfall for their livelihoods, limited access to and affordability of agricultural tools and inputs, and the increasing rates of poverty. The susceptibility of agricultural production to climate change can lead to food insecurity, while also diminishing the actual income of farmers (Dhakal *et al.,*2022). Smallholder farmers are more susceptible to climate change related impacts, which increases their total income loss (Zakari *et al.,* 2022). In Ethiopia, hundreds of thousands of smallholders have been forced to relocate to marginal areas where there is little access to irrigated fertile land and where climatic shocks are more common (Ketema *et al.,* 2022). Due to climatic and associated factors, Ethiopian rural farmers' income is expected to fall by 20.4 % by 2050 (Solomon *et al.,* 2021). Hence, these farmers are relatively susceptible to climate risk, which reduces farm profitability (Ketema *et al.,* 2022).

2.2.3. The impacts of climate change on food security

Climate change is expected to have a negative impact on agricultural systems, particularly in Africa where agricultural practices heavily depend on rainfall and temperature (Mekonnen *et al.,* 2021). Furthermore, it is worth noting that such nations in the Sub-Saharan Africa countries including Ethiopia are heavily dependent on agriculture and activities related to natural resources. These sectors are particularly exposed to the negative effects of climate change. Furthermore, farmers low adaptation capacity to climate change exacerbates their vulnerability to its impacts (Akinnagbe and Irohibe, 2014; Addisu *et al.,* 2019).

Climate change affects soil moisture and organic matter all of which reduce agricultural yield (Sida *et al.,* 2018). In developing countries, where farmers depend heavily on rain-fed agriculture, the favorable climate is a valuable resource for both crop and livestock productions (Birara *et al.,* 2015; Weldearegay and Tedla, 2018). The growing evidence from the scientific community also suggests that climate change is reducing crop yields in developing nations by raising temperatures and altering precipitation patterns (Alemu and Mengistu, 2019). The prevalence of food insecurity in rural Ethiopia is closely linked to changing weather conditions, which are seasonal and tied to rainfall (WFP, 2014).

About 42% of Ethiopia's GDP comes from subsistence farming, which has a substantial impact on the country's economic growth (CSA, 2018). In addition, the country is particularly sensitive to the effect of climate change for three key reasons, (a) approximately 80% of total people depends largely on rain-fed agriculture; (b) it is a developing nation with a low per capita income; and (c) its diverse geographical locations experience climate change at varying intensities (Alemu and Mengistu, 2019). The country's susceptibility to the adverse effect of climate change on its agricultural sector is attributed to the interplay between its location, topographic features, and adaptive capacity (Addisu *et al.,* 2019). Therefore, many of the Ethiopian community experiences chronic and temporary food insecurity, which is closely connected to critical and chronic food shortages and famines caused by frequent droughts (Mota et al., 2019).

Most of the households without access to adequate food supplies are found in the southern part of Ethiopia, an area notable for its susceptibility to drought related famine (Mota *et al.*, 2019). Climate and agricultural productivity are clearly related: climate change has adverse effects on food systems in all areas (Adugna *et al.*, 2016; Tafesse *et al.*, 2016). In addition, climate-related shocks have the potential to decrease productivity, impede economic growth, and worsen existing societal and financial problems (Carleton and Hsiang, 2016).

2.3. Farmers' perceptions of climate change and the use of CSA practices as an adaptation strategy

The need of adaptation to both current and anticipated climate change is crucial for farmers to reduce the negative effects that climate change has on agricultural practices (Pörtner *et al.,* 2022). Adopting measures depends on how farmers perceive climate change and variability (Teshome *et al.,* 2021). Limited availability of climatic information and extension services, coupled with limited understanding and knowledge of climate change and variability, result in a lack of motivation to adopt new farming practices (Sertse *et al.,* 2021). Smallholders' knowledge and perception of climate change consist of information and understanding of climatic risks, which are essential for climate change adaptation (Nguyen *et al.,* 2019). In this regard, the simplicity of farmers' knowledge and observation toward climate change is mainly characterized by personal opinions with inadequate scientific evidence (Hundera *et al.,* 2019).

The scientific literature suggests that there are significant gaps in understanding public opinion and perception of climate change, which arise from the subjective nature of measuring climate change. It is crucial to address these gaps by providing scientific evidence (Ringler *et al.,* 2010; Silvestri *et al.,* 2012; Howe *et al.,* 2019). Farmers' perceptions of climatic changes alone may not guarantee adaptation measures; several other reasons may threaten their ability to adapt (Jha and Gupta, 2021). Farmers' ability to adapt is determined by their knowledge and cognitive skills, which vary across families and are affected by demographic factors such as age, family size, farm size, educational level, gender, geographic location, and other socioeconomic aspects (Belay *et al.,* 2017; Fierros-González *et al.,* 2021; Talanow *et al.,* 2021; Jha and Gupta, 2021).

Adaptation is the local response to climate stimuli, which should resolve the critical gaps, i.e., farmers' perceptions and understanding of the changing climate (Ricart *et al.,* 2022). Disregarding the importance of knowledge and perceptions in farmers' adaptation decisions could be counterproductive as farmers' response process behavior could help address their economic, socioenvironmental problems (Ng *et al.,* 2010; Jellason *et al.,* 2019). Measuring farmers' knowledge, behavior, and perceptions regarding climate change is a complex task to be visualized and examined in a different approach. Some scholars hypothesize that perceptions come before any adaptation interventions taken in response to climate change and variability (Singh *et al.*, 2017; Bradley *et al.,* 2020).

2.4.Adoption of CSA practices

Climate change threatens agriculture, food supply, and employment for millions of people worldwide, particularly in Africa (Makate, 2019; Leisner, 2020; Atwoli *et al*.,2022). Community livelihoods have been impacted by changes in average temperatures, shifts in rainfall patterns, and the intensity and frequency of extreme events like floods and droughts (FAO, 2021; Zougmoré *et al.,* 2021). Agricultural production systems, including agroforestry, livestock, and crops, need to adapt to climate change and establish resilient livelihood systems to secure the food and livelihood of rural communities (FAO, 2016; Crippa *et al.,* 2021).

The 'International Center for Tropical Agriculture (CIAT)' (2017) report that climate change has the potential to cause a significant decline (8–10%) in the GDP of Ethiopia by the year 2050. However, it has been suggested that implementing adaptation measures in agriculture could potentially reduce losses caused by climate shocks by up to 50%. To reduce the severe climatic risks, agriculture has several effective adaptation options. The scientific community is widely advocating CSA practices to transform agricultural systems in a changing climate (Omilola and Robele, 2017; Khonje *et al.,* 2018; Crippa *et al.,* 2021). Climate smart agriculture is widely promoted to improve agriculture under the face of CC (FAO, 2013). FAO (2010) and Lipper et al. (2014) state that CSA is a strategy that aims to improve food security under climate change by altering agricultural systems and offering adaptable, socially acceptable, and context-specific solutions.

The CSA approach's guiding principles are as follows: Increasing agricultural and food system resilience to climate variability and change; (ii) boosting equitable improvements in farm income and food security through sustainable productivity and development; and (iii) reducing GHGs emissions from agricultural activities (crop, livestock, fisheries, and so on) (FAO, 2010). Climate smart agriculture encompasses various agricultural practices and technologies which are described in different literatures such as soil and water conservation (SWC) with biological measures, integrated practices of fertility of soil and its management (e.g., soil mulching and crop rotations), livestock breeds, agroforestry systems, conservation agriculture, crop diversification and improved pasture lands (Suckall *et al.,* 2015; FAO, 2013).

Recent studies indicate that CSA as an approach can enhance food self-sufficiency, biodiversity, and livelihoods in the challenge of climate change. Studies have shown that implementing various CSA measures can have positive impacts on revenue, production, and food security in diverse settings. Implementing stress-tolerant crop varieties and early warning services has been proven to boost crop yields, incomes, and food self-sufficiency (Lipper *et al*., 2014; Anderson, 2018; Makate *et al*., 2019; Lunduka et al., 2019). Diversifying agriculture systems can also lead to increased crop-livestock production and other livelihood gains. Adopting farming systems that improve yields and livelihoods has shown positive results (Mango *et al.,* 2017). Additionally, the practice of agroforestry systems has been strongly linked with higher incomes, livestock holdings, and improved household food (Bostedt *et al.,* 2016; Leisner, 2020). Furthermore, CSA provides additional co-benefits that can considerably accelerate CSA policies and mainstream adaptation and mitigation actions to increase resilient livelihood diversification (IPCC, 2014; Suckall *et al.*, 2015).

Despite the wide range of applications for CSA measures and technologies, the adoption rates among African farmers remain relatively low (Palanisami *et al.*, 2015). The low rate of CSA adoption can be attributed to various factors. These include the socioeconomic characteristics of farmers, the bio-physical environment in which they operate, the absence of proof or success stories regarding CSA adoption in agricultural systems, the lack of sound policies strategies, and the specific characteristics of new technologies (Nyasimi *et al.*, 2017; Aggarwal *et al.*, 2018; Aryal *et al.*, 2018).

The main challenges in scaling up CSA in different agro-ecological locations focus in identifying, prioritizing, and promoting current CSA practices and technologies. These challenges need to be addressed while contemplating local climate risks and the requirement for such technologies (Stuch *et al.,* 2021). For instance, in many Eastern African countries, such as Ethiopia, the current climate change adaptation programs lack comprehensive information on adaptation planning, despite the need to prioritize CSA options at the farm level (Ayinu *et al.*, 2022). Lipper *et al.* (2014) report that farmers are adopting CSA interventions relatively slowly in Africa, notably so in Ethiopia, and argue that research and policy support should be strengthened. According to Tigabu and Gebeyehu's (2018) study on agricultural extension services and technology adoptions in Ethiopia, adaption strategies require new policy frameworks and novel approaches.

Prioritizing farms can help key stakeholders make smart choices that are compatible with institutional frameworks and governmental rules (Nyasimi *et al.,* 2017; Senyolo *et al.,* 2018). Institutional and policy reforms are necessary for adopting CSA initiatives. For instance, enhancing institutional support and policy to enable farmers to use CSA innovations, as well as offering essential agricultural inputs, financing, consulting services, and sustainable markets, can all contribute to the widespread adoption of CSA on farms and in landscape level (Khatri *et al.*, 2017; Makate *et al.*,2019). Hence realistic institutional and policy measures are required to implement and scale up CSA practices.

2.5. Impacts of CSA practices on farmers income and food security

Smallholder farmers are extremely vulnerable to the effect of climate change and variability, which threaten their agricultural-based livelihoods. Efforts are underway to promote CSA practices and technologies to help smallholder farmers in adjusting to climate change (Mujeyi *et al.,* 2021). The implementation of CSA is a crucial measure in enhancing the welfare of farmers in developing countries that are dealing with the challenges of climate change and limited agricultural land for expansion (Khatri *et al.,* 2016). The implementation of CSA has effectively enhanced the overall welfare of rural communities. This is particularly true for farm households that possess sufficient capital, robust social networks, and well-integrated food markets (Bazzana *et al.,* 2022).

Overall, CSA plays a critical role in ensuring food security, fostering economic growth, and alleviating poverty (Ouédraogo, *et al.,* 2019). Improved agricultural practices can lead to better household welfare through income growth and enhanced food security (Sani and Kemaw, 2019). Previous studies assessed the impacts of CSA technologies including improved crop varieties in Kenya (Ogada *et al.*, 2020), manure composting in Tanzania (Pamuk *et al.*, 2021), improved maize in Zambia (Khonje *et al.*, 2015), improved wheat and sorghum in Ethiopia (Tesfaye *et al.*, 2016; Wake *et al.,* 2019), improved livestock breeding in Rwanda (Habiyaremye, 2017), SWC in Somalia (Nyirahabimana *et al.*, 2021). Farmers who implemented CSA measures were shown to be more food secure in terms of 'Household Dietary Diversity Scores (HDDS), Household Food Consumption Score (HFCS)', and household income.

For example, adopting drought-tolerant maize crops has increased yields by 13.3% while lowering risk by 81% in rural Nigeria (Wossen *et al.*, 2017). Farmers who adopted different CSA packages that included improved crop variety, risk reduction strategies, and specific SWC activities were 56.83% and 25.44% more food sufficient compared with non-adopters in terms of HFCS and HDDS respectively (Wekesa *et al.,* 2018). The implementation of different crops that are more resistant to stress resulted in an 83% increase in household income (Ogada *et al.,* 2020). Smallholder farmers in Ethiopia have implemented a multitude of CSA measures to climate change impacts and to safeguard agricultural productivity, poverty reduction, and food security (Di Falco and Veronesi, 2018). These measures include improved crop varieties, SWC with biological measures, agroforestry, minimum tillage/mulching, and irrigation schemes. The recent study on the effects of CSA and have found both direct and indirect impacts in Ethiopia (Bazzana *et al.*, 2022). The direct effects include improved productivity of crops and livestock. On the other hand, the indirect effects include enhanced food security due to the increase of staple crops and income of the household.

Ethiopian government produced the 'Climate Resilient Green Economy (CRGE)' strategy document in 2011 to meet the 2025 target of middle-income countries. To address the pressing problem of climate change, the policy document calls for the adoption of CSA options, which will improve household income, food security, and carbon emissions reduction.

The Ministry of Agriculture undertook a national effort to promote row planting of cereal crops through the Agricultural Transformation Agency (ATA); around 2.5 million farmers participated in this campaign (Fentie and Beyene, 2019). The Ten-Year Development Plan (2021 - 2030) is the most recent major development strategy in Ethiopia (Minot, *et al.*,2021). As stated in the Plan's description, the main objectives are to increase the incomes and livelihoods of farmers and pastoralists and to end poverty by making agriculture more productive and competitive; to play a significant part in the structural transformation of the economy, particularly in satisfying the nation's food and nutritional needs by modernizing agriculture; to supply raw material inputs for the agriculture sector; and to provide rural employment opportunities (Wayessa, 2021).

Despite its importance, the productivity of agriculture in Ethiopia is insufficient and cannot feed the current population. The agriculture sector is challenged by extended droughts, irregular rainfall, soil erosion, low input supply, and limited technology adoptions. Due to limited cultivated land and insufficient inputs supply, and manpower requirements, the adoption rate of improved agricultural technology, performance, and productivity in Ethiopia remain unsatisfactory (Yu and Pratt, 2014). Ogunyiola *et al.* (2022) indicate, CSA practices such as improved crops have been implemented and are enhancing food security and household income. To successfully implement CSA practices in agriculture, multiple stakeholders' approach is required such as extension agents, practitioners, policymakers, scientific communities, and other relevant actors (Ogada *et al.,* 2020).

The 'Consortium of International Agriculture Research Center (CGIAR) research program on Climate Change, Agriculture, and Food Security (CCAFS)' has been collaborating with smallholder farmers in Eastern Africa, specifically in Ethiopia, promoting a range of CSA measures via a 'climate-smart village' approach to scale up improved agricultural technology and support policy options (Ogada *et al.,* 2020). Adaptation can take place either from the bottom up, where it is based on actual concerns and is driven by demand, or from the top down, where it is centralized and driven by policy (IPCC, 2014). Scientific evidence shows CSA practices increase the productivity of agricultural and these increments can improve household income, food security (Aggarwal *et al.,* 2018; Mujeyi *et al.,* 2021). Some studies have provided empirical evidence showing that CSA adoption benefits outweigh conventional methods of farming systems (Wake *et al.,* 2019; Ogada *et al.,* 2020).

However, studies on the effects of CSA practices, particularly for income and food security from Ethiopia's perspective, remain limited as the adoption intervention has been observed to be location specific (Zerssa *et al.,* 2021; Kassaye *et al*., 2022; Khoza *et al.,* 2021). Several CSA practices are adopted in various landscapes in Ethiopia; nevertheless, the impact studies are not well understood nor scientifically documented (Fentie and Beyene, 2019; Issahaku and Abdulai, 2020; Zerssa *et al.,* 2021; Mekonnen *et al.,* 2021). The adoption of CSA practices could be affected by access to climate information, limited inputs supply, lack of institutional support, and inappropriate technology (Partey *et al.*, 2018; Ogada *et al.,* 2020; Zerssa *et al.*, 2021). Furthermore, lack of evidence or a knowledge gap may cause CSA practices or technologies to take longer to catch on, which will have a poor effect on livelihoods (Asfaw *et al.,* 2012; Ullah *et al.,* 2020).

2.6. Strengths and challenges of Climate Smart Agriculture

Climate change adaptation is a two- step process: the first step requires farmers to recognize that the climate is changing, the second step involves applying adaptation strategies (Li *et al.*, 2021; Mirzabaev, 2018). Morton (2007), Teklewold *et al.* (2019) and Fierros-González and Lopez-Feldman (2021) emphasize the importance of farmers understanding climate variability to improve agricultural practices, such as implementation of CSA practices and technologies. In this regard, different theories of perception have been reviewed to understand farmers' awareness of climate change.

The theory of planned behavior (TPB) is used to construct rural farmers' perceptions and behavioral control over present climate change and variability. (Ajzen, 1991). Theory of planned behavior is analyzed from three aspects: (1) attitudes toward behavior, subjective norm, and perceived behavioral controls; (2) associated with farmers' cognition of climate change perceptions; and (3) aspiration of technology adoptions. Aspiration is the reference point for farmers to achieve the target of desire that improves the farming system by adopting CSA practices. The motivation of farmers is to achieve the target of improving agricultural production for bettering their lives against climate change risks (Duan *et al*., 2021). Farmers' aspirations in agriculture production are based on, for example, aspiration window, gap, capacity, and failure (Nandi and Nedumaran, 2021).

The aspiration window denotes that the farmers' cognitive dimension draws aspiration in their domain. Meanwhile, the aspiration gap is what farmers aspire to and what they can achieve, whereby such gaps affect their future. Rogers's (2004) theory of diffusion summarizes the main factors influencing farmers' aspirations and decisions over their CSA adoption process. This includes the innovator who takes the risk of using new farming technologies, the ways of information dissemination for early adopters, the time conditions that early majority was convinced for CSA adoption, the skeptical characteristics of farmers who seek evidence of adoption benefits, and the poor farmers who are suspicious of new farming technologies. The theory assumes that farmers' willingness to accept, and information access are the main factors influencing farmers' adoption decisions. However, previous studies show many factors affecting farmers' adoption of agricultural innovation. For example, Wheeler *et al*. (2013) argued that social, biophysical, economic, human, institutional, demographic, and farm variables influence farmer behavior. In addition, Owusu *et al*. (2017) and Jethi *et al.* (2016) state that climate and non-climactic factors determine the agricultural productivity performance of farmers.

According to Janzen *et al*. (2017), farmers who have high aspirations and internal locus of control are forward-looking and tend to benefit their families and communities' resilience toward climate shocks. Farmers' belief of climate change and their decision to take CSA measures is associated with the internal locus of control and their aspiration (Knapp *et al*., 2021). Climate extremes have become more frequent and intense; thus, smallholder farmers feel the impacts and contemplate their future, leading to aspiration failure and cognitive depression. Understanding farmers' perception can be considered a precondition for designing and successfully implementing the selected agricultural innovations (Carlos *et al*., 2020). Effective implementation of such interventions requires proper institutional arrangements and clear policy directions that enhance the CSA adoption and its effectiveness among rural farmers.

Hellin *et al*. (2021) suggest that CSA practices should bring farmers, researchers, policymakers, and relevant stakeholders together and investigate the existing practices and new agriculture technologies in adaption to current climate change and variability. Farmers have a mixed knowledge of climate change; some farmers perceive it, whereas others do not. Farmers' decisions regarding climate change adaptation are influenced by their knowledge and understanding of climate change and variability.

Farmers' responses to adaptation decisions, on the other hand, may be motivated by external as well as internal factors (e.g., education, farming experience, household size, landholding size, livestock ownership institutional services, social network, and market infrastructure). These factors could be a constraint for farmers to participate in the adaptation process (Below *et al*., 2015). Similarly, not all farmers take improved adaptation measures, and farmers' adaptation to climate change is affected by external and internal factors that determine their adoption ability. In this regard, examining farmers' understanding of climate change and their response intentions by integrating socioeconomic and biophysical factors needs to be explored. This would contribute to more social desirability and networking, access to valuable climate information, and improved knowledge and understanding of farmers' adaptation behavior. Adaptation constraints (e.g., lack of knowledge, limited input supply, poor institutional support, and money shortage) provide potential entry points for CSA adaptation policymaking and its implementation (von Braun and Birner, 2017; Ogada *et al*., 2020).

Adoption of CSA is important to improve farmers' welfare under the threats of climate change (Boz and Shahbaz, 2021; Sardar *et al*., 2021). Implementing CSA practices and technology can greatly benefit smallholder farmers by helping them achieve food security, enhance their income, and alleviate poverty. Recent research indicates that enhancing agricultural yield has the potential to positively impact farmers' well-being by boosting household income and ensuring better food security (Ogada *et al*., 2020; Warinda *et al*., 2020; Hussain *et al*., 2022; Ogunyiola *et al*., 2022; Musafiri *et al*., 2022).

CHAPETR THREE: STUDY AREA, DATA AND METHODS

3.1. Introduction

This chapter first introduces the study area, describing biophysical and socioeconomic settings, land use and resources, and climate vulnerability and adaptation. The chapter then presents the conceptual framework and the methodological approach, including objectives, data gathering tools, and models for data analysis.

3.2. Study area location and description

This study was carried out in the Doyogena district, which is geographically located between 7°17′-7°19′ N latitude and 37°45-37°47′ E longitude, and administratively in Southern Nations, Nationalities, and Peoples Region of Ethiopia (Figure 3.1). The altitude varies between 2420 and 2800 meters above sea level. Farmers' main source of income is mixed agriculture (crop-livestock agricultural systems). The area produces legumes, cereals, fruit trees, vegetable root crops, and perennial crops such as Enset/false banana (*Ensete ventricosum*). Enset is a widespread drought-tolerant and multifunctional crop that yields a high-calorie meal known as "Kocho," which is cultivated by practically every farmer in the study site. Livestock production in the study area includes cattle, sheep, and poultry (Belay *et al.*, 2021; Tadesse *et al.*, 2021).

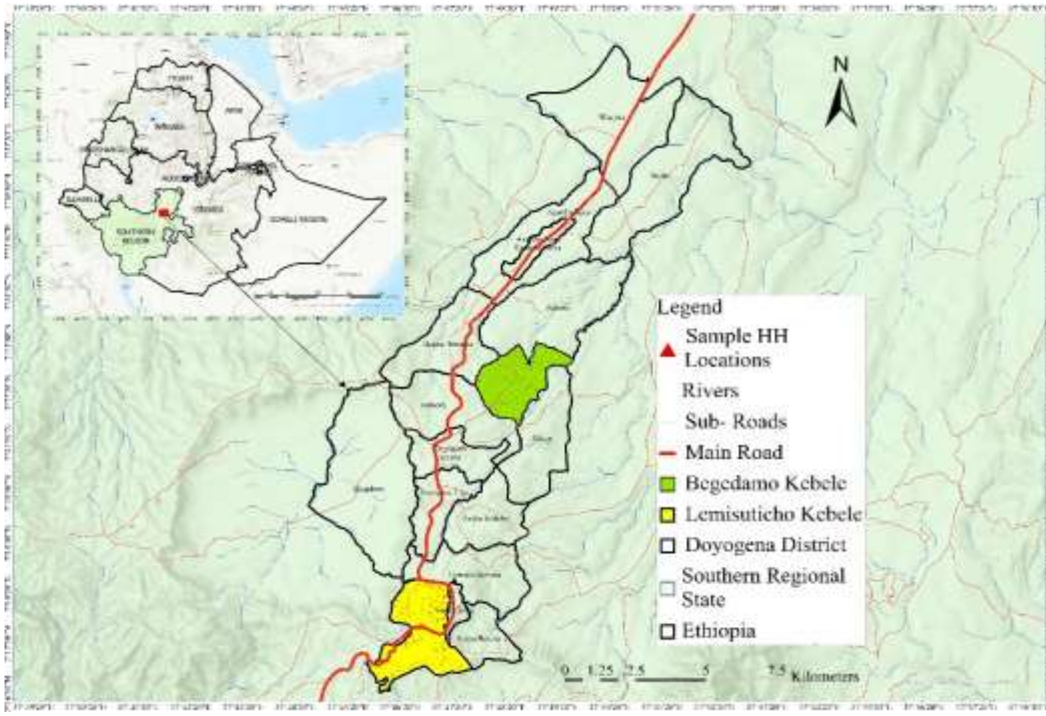


Figure 3.1 Map of the study area (author's own work, 2022)

The research site is susceptible to extreme weather events including drought and flooding, which can lead to severe water scarcity, soil erosion, land fragmentation, shortages of feed for animals, diseases of crops and livestock, deforestation, and land degradation (Taye *et al*., 2016; Bonilla *et al*., 2020; Tadesse *et al*., 2021).

According to a Central Statistical Agency report, the number population for the study district is estimated 122,336 between 2007 and 2015, with 51% males and 49% females and the average population density per square kilometer was 458 (Central Statistics Agency (CSA), 2013). The study sites have diverse crop-livestock agricultural systems with different topography. Various ethnic groups (e.g., *Kembata, Hadiya, Wolaita, Tembaro, Gedio,* and *Guragie Halaba)* live together, settling in different villages, and sharing values, cultures, religions, and food systems (Melketo *et al*., 2020). The agricultural system in the research area is completely dispersed. Following the demographic growth and parcelling out of the farm plot, most existing settlements established at the top of the hills are ideally suitable for growing various crops. To reduce the effect of climate change on smallholder farming systems in the study area, CSA initiatives are being implemented by the development partners such as the CCAFS, and InterAide.

In the study district, farmers have been using CSA practices for a decade (2012), with the help of partners and the local government. InterAide, for example, launched a pilot project in several villages in 2006 to address climate-related impacts in the study region. Later, in 2012, the 'CGIAR project Africa Research in Sustainable Intensification for the Next Generation' (commonly known as Africa RISING) was launched, with the goal of expanding to other CSA villages.

3.3. Biophysical Setting

The sections below present the biophysical settings of the study area which includes climate, vegetation, land use and resources, physiography and drainage, water resources and biophysical vulnerabilities.

3.3.1. Climate

The Doyogena district in the southern region has a humid climate, with an average annual rainfall of 1500 mm. The area has highly variable weather conditions with bimodal rainfall seasons namely, *Kiremt* with peaks June-September (long rainy season); and *Belg* season from February-April (short rainy season). The average temperature varies between 12°C and 20°C annually, while the rainfall varies from 972-1500 mm (Belay *et al*., 2021). The two rainy seasons are referred to as *mate'haa sana* and *glalichi sana* in *Kambattis* and K*iremt* and *Belg* in Amharic respectively (Belay *et al*.,2021).

3.3.2. Vegetation

The study area has an abundance of vegetation, with domestic tree species including *Podocarps falcatus, Acacia abyssinica, Olea Africana, Cordia africana, Croton macrosachyus,* and *Juniperus procera* among others. These tree species are used for firewood and timber production. Farmers, for example, grow *Eucalyptus globules* for construction, firewood, and timber production. The farmland of the smallholders is surrounded by broad leaf agroforestry, which consists of woody perennials such as *Ensete ventricosum* plantation is used as hedging and live fencing safeguarding the farmers crop from animal damage (Demalo,2014; Erchafo, 2018).

3.3.3. Land use and resources

The economic setting of the area depends on subsistence agriculture and livestock systems. In the district, from 1973 to 2020, the proportion of forestland plummeted from 1756.7ha (38.8%) to 71.6ha (1.6%). Wetland areas, for example, have shrunk from 16.8 ha/year between 2000 and 2010 to 6.3 ha/year between 1986 and 2020. Contrarily, cropland increased from 34.1% in 1986 to 2000 to 46.3% in 1986 to 2020 (Mariye *et al.*,2022). The average size of landholding possessed by both male and female farmers is approximately 0. 75ha (Mathewo *et al.*,2021). The area's livelihood systems are based on agriculture, cattle, and the production of pasture for animal feed. In the study area, settlement is often found at the top and bottom of the hill, and due to the large population density, some households also build their homes on the mid-slope. The study site is described by the growing of various crops such as *Enset*, wheat, potato, and legumes. Farmers plant productive forage plants such as *Desho Grass* (*Pennisetum pedicellatum*) to feed their livestock and to overcome the shortage of grazing lands (Erchafo, 2018).

3.3.4. Physiography and Drainage

The area consists of a large network of rivers which ensures the region's good drainage in the Bilatie watershed. Four of the rivers (Sana, Yabela, Bilatie, and Shanya) are permanent, while the other three are intermittent (Shapa, Gondala, and Kasho) (Mariye *et al.*,2022). The Sana, Yabela, Bilatie and Shanya rivers have a constant flow of water all year and eventually join into the Omo Basin. The area exhibits a varied and steep topography with elevations that span from 2420 to 2800 meters above sea level. The slope of farmland varies from 2% to 65% where agricultural activities are practiced, and the terrain slope is classified into three major types, namely normal, moderate, and steep slopes, which account for 10.7%, 63.9%, and 25.4%, respectively (Mariye *et al.*,2022). This geographical feature contributes to considerable soil erosion and the creation of gullies.

3.3.5. Water resources

The area has sources of domestic water from rivers, and groundwater from shallow and dug wells. The area is rich in tributaries and rivers. According to the ministry of water and energy information or data on the total water supply in the region, about 60% of them are functional and the remaining 40% are not (Abera and Wana, 2023). The average urban and rural area water supply reaches about 75% and 49% respectively (Demalo, 2014; Tadesse *et al.*,2021).

3.3.6. Biophysical vulnerabilities

The productivity of crops and fodder in the district are contingent upon the amount of rainfall received, which is known to be unpredictable. The variabilities in these occurrences can be observed through their frequency, severity, spatial extent, length, and timing. The effect of climate change on farming systems is generally observed through both direct and indirect effects (Gitz *et al*.,2016). Direct effects are those that have an immediate impact on certain agricultural production systems, such as shifts in temperature and rainfall. Unpredictable rainfall patterns have a major effect on land degradation and soil erosion, which eventually results in lower land productivity. Indirect effects are those that have an impact on production by affecting different species such as pollinators, pests, disease vectors, and invasive species.

Rainfall variability is considered as one of the highest causes of risk and vulnerability in the area (Belay *et al*.,2021; Mariye *et al.*,2022). Additionally, water scarcity, free grazing, soil erosion (from both water and wind), land fragmentation, animal feed shortage, livestock disease, deforestation, and barren land because of soil degradation are the most frequently reported problems (Tadesse *et al.*, 2021; Abera and Wana, 2023). The combination of steep topography and irregular rainfall causes extensive erosion of open fields as well as significant erosive run-off. Within the study area, there is an increasing trend of severe deforestation and vegetation clearing. This is primarily driven by the need to acquire more cultivable land and grazing pastures. However, it is important to note that these activities are exacerbating the problem of soil erosion. In the context of mountainous steep slope environments, the replacement of forests and grasslands by farming results in significant soil deterioration (Demalo, 2014; Melketo *et al*., 2020; Tadesse *et al.*,2021).

3.4. Socioeconomic Setting

This section highlights the political and administrative context, the national/regional/local economic environment, the social environment, the health environment, the regulatory framework, and socioeconomic vulnerabilities.

3.4.1. Political and administrative context

The Doyogena district is located in the 'Kembata Tembaro zone of the Southern Nations, Nationalities, and Peoples Region in Ethiopia'. The place is located 258 kilometers south of Addis Abeba and 171 kilometers Southwest of Hawassa. The study area has about 217km weather roads and 140km dry weather roads. The road density of the area is 249 km per 1000km^2 (Teketel *et al.*,2021).

3.4.2. National/regional/local Economic setting

The area has different socioeconomic problems, and this creates poverty in the local community including insufficient labor production due to migration to urban areas. The regional government has been working different economic activities focusing on job opportunities and poverty reduction activities like development projects such as industrial parks, educational and health centers, green infrastructure (Teketel *et al.*,2021).

3.4.3. Social setting

The federal and regional government has designed different strategies to safeguard the most vulnerable part of societies and social protection programs have been in place to safeguard the communities. For instance, the country's food security program has been designed in various ways to effectively address the issue of scarcity and benefit a significant portion of the population. This food security program is aimed to create employment opportunities for youth and women (Teketel *et al.*,2021).

3.4.4. Health setting

The country's health policy has been adopted in the way to as the response of the people's need for basic health services. The health extension program is one of the newly established programs that could serve better the needs of the community with special attention to mothers and children focusing on the rural areas. In the region, about ten hospitals and many health centers have been built by the federal government to enhance the safe motherhood program (Lafore *et al.*,2021).

3.4.5. Regulatory Framework

After Ethiopia's military regime was overthrown in 1991, the constitution was enacted in 1995. The Extension programs enhance agricultural productivity economically and elect more farmers politically. The Ethiopian extension system uses a bottom-up, Farm Training Center (FTCs) based agricultural extension method along with farmer organizations like One-in-Five and development units, which are regarded as the entrance point for grassroots extension services (Leta *et al*., 2017). FTCs are required to provide a wide range of agricultural extension services through an innovative and sustainable farmer-owned agricultural extension system with the help of development agents and farmer groups.

The country's agricultural strategy aims to increase output and facilitate political control, both of which are believed to be necessary to win elections. A study at the community level has identified a few root causes for the ineffectiveness of agricultural extension services, including weak links between research and agricultural extension, policies that are not tailored to the needs of small holders, and the lack of involvement of agricultural extension workers in activities (Hoben, 1995; Keeley and Scoones, 2000).

3.4.6. Socioeconomic vulnerabilities

The socioeconomic vulnerability in the region is exacerbated by its high level of poverty and reliance on major industries that are expected to be affected by climate change: agriculture, water, tourism, and forestry (World Bank, 2021).

While the region is subject to natural risk such as sudden flooding and drought, its topographic variety and heavily marginalized populations make it even more vulnerable. Non-climate stresses such as inadequate infrastructure to handle the growing population are also influencing climate change vulnerability. The frequent droughts and floods have had a substantial impact on poverty, food security, livelihood status, and community human capital. In response of the above-mentioned problems, local farmers are applying a multitude of CSA practices including integrated watershed management and landscape rehabilitation, improved crop and livestock production, cereal and legume rotation and agroforestry practices are some of the current activities being implemented (Belay *et al.*, 2022; Tadesse *et al.*,2021).

3.5. Conceptual Framework

Recent studies indicates that the adoption of new agricultural technologies and practices is influenced by the possible risks and uncertainties associated with climate change. According to the expected utility theory assumptions, farmers who make decisions to adopt new agricultural technology, such as CSA practices, consider the risks, uncertainties, and farm input constraints that may affect their utility maximization(Jaeger, 2007; Mercer, 2004). The decision to maximize utility or profit is a function of farmers' preferences or selection from the available alternatives, which include CSA practices and technologies (Marra *et al.*, 2003; Wens *et al.*, 2021).

The adoption theory demonstrates that farmers' resource allocation decisions for different agricultural practices are subject to maximizing the expected utility of food and income by selecting specific CSA practices under risks and uncertainties(KW Maina *et al.*, 2020). In this study, for example, smallholder farmers expect benefits or utilities from adopting CSA practices that maximize their income and food security (Sardar *et al.*, 2020). Smallholder farmers adopt new agricultural practices and technology if the expected utility or benefits from adoption (*Ua*) are substantially greater than the expected utility or benefits from non-adoption (*Un*) (Kassie *et al.*, 2015; Ngoma *et al.*, 2021).

Following Wooldridge (2010) and Greene (2003), as indicated in (Equation 1), we derived the utility function from the adoption of CSA with dichotomous choices, which are determined by the given observable and unobservable characteristics of Z_i and the error term $\boldsymbol{\varepsilon_i}$, such that

$$I^{*}i = \beta Z_i + \mathcal{E}_i,\ I_i=1 \quad \text{if} \quad I^{*} > 0, \text{ and } 0 \text{ if otherwise} \qquad (1)$$

where I_i represents a binary choice variable for CSA adoption, which equals 1 if the farmers I adopt the CSA practices, and 0 otherwise. β represents the coefficient of the vector parameters to be estimated, Zi represents socioeconomic characteristic of the farmers, and εi is the error term. Therefore, farmers adopt CSA practices if $I_i = Ua - Uu > 0$. Hence, the probability of households' adoption of CSA practices and technology would be quantified in Equation 2 as follows:

$$\Pr (I_i = 1) \text{ and } \Pr (I^{*}I > 0) = 1 - D(\beta Z_i) \qquad (2)$$

where $((I_i=1)$ represents the probability of CSA adoption, and D is the cumulative distribution function for the error term($\mathcal{E}_i$), which differentiates the types of model used for estimation (Greene, 2003).

Adoption of CSA is critical for improving farmer welfare in the face of climate change threats (Boz & Shahbaz, 2021; Sardar *et al.,* 2021). Adopting CSA practices and technology can assist smallholder farmers in achieving food security, increased income, and poverty reduction. According to recent research, increasing agricultural yield can improve farmers' well-being by increasing household income and food security (Hussain *et al.,* 2022; Musafiri *et al.,* 2022; Ogada *et al.,* 2020; Ogunyiola *et al.,* 2022; Warinda *et al.,* 2020).

This study's conceptual framework is built around four main components: i) climate change /variability and its effects; ii) adoption of CSA; iii) crop yield increment; and iv) household income and food security. The conceptual framework follows a top-down approach indicated (Fig. 3.2). The lines connecting the boxes with positive and negative signs show the impacts of each component on the other components in different ways. Climate change and variability harm smallholder farmers' livelihoods because their livelihoods are vulnerable to climate-related risks and have poor adaptive capacity (Ogada *et al.,* 2020).

Climate-related impacts can be mitigated by adopting CSA practices and technology on agricultural land (Warinda *et al.*, 2020). Effective and timely adoption of CSA practices on farming plots depends on knowledge and perception of climate change and its consequences (Boz & Shahbaz, 2021). Moreover, the intention of farmers to adopt available CSA practices is influenced by experience, socioeconomic and intuitive support, infrastructure, and sound policies(Ruben et al., 2019). The advantages of CSA adoption have a direct positive effect on farmers' income growth and mitigate the adverse effects of climate change and variability (Hussain *et al.,* 2022). Moreover, farmers' decision to adopt CSA practices tends to reduce climate risk, increase crop yield, improve household income, and satisfy the demand for farmers' food consumption (Ogunyiola *et al.,* 2022).

In contrast, if farmers failed to adopt CSA measures and instead practiced conventional farming, it could lead to an increase in climate risk vulnerability and a decline in crop yield per hectare (Sardar *et al.,* 2021). Smallholder farmers can reduce climate-related losses and damages by incorporating CSA practices into their farming system (Musafiri *et al.,* 2022). Smallholder agriculture productivity and crop income ultimately enhance household food security, but farm income and food security enhancement is contingent upon CSA interventions (Sedebo *et al.,* 2022). Therefore, the conceptual framework of this study began with climate change and its effects on farmers' agricultural practices, as well as the direct implication of CSA adoption on household income and food security (See Figure 3.2).

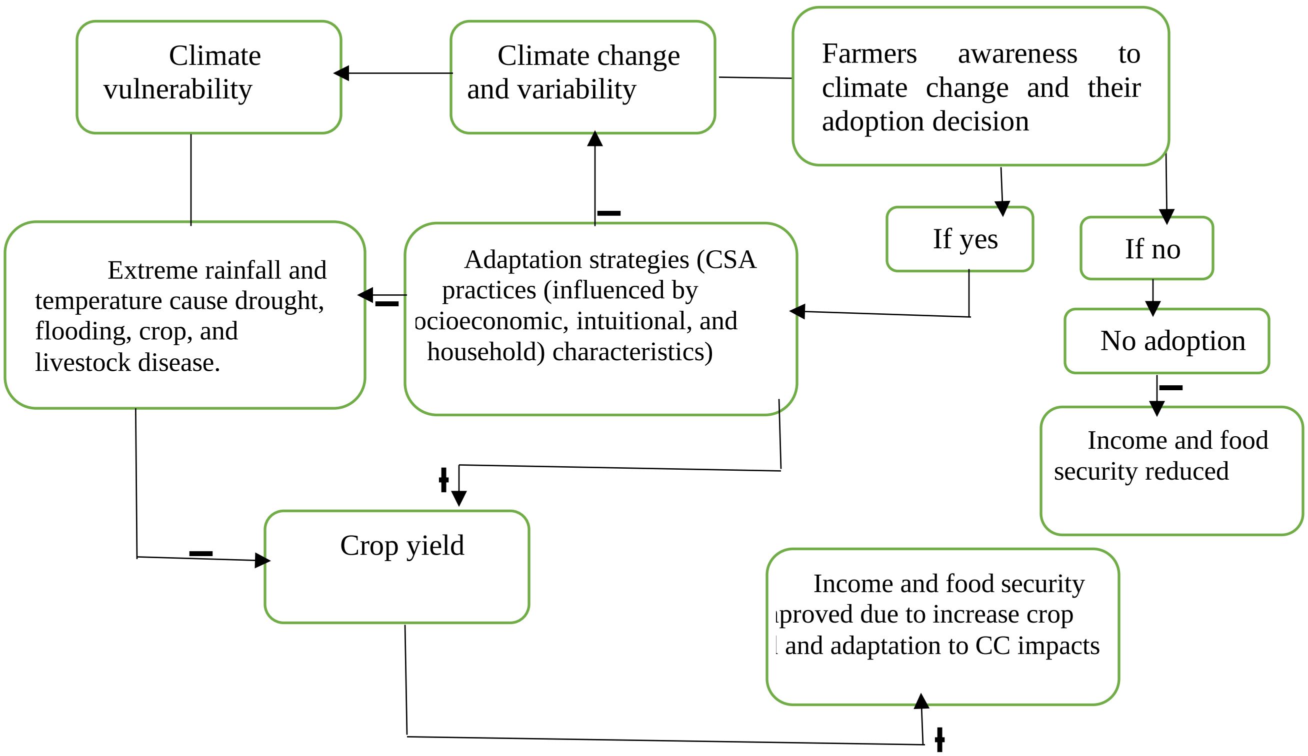


Figure 3.2: Conceptual framework of the study

Sources : adapted from Sarda *et al*. (2021)

Climate-related impacts can be reduced through the implementation of CSA measures and technology on farming plots (Warinda *et al*., 2020). Effective and timely adoption of CSA practices at farming plots depends on knowledge and perception of climate change and its effects (Boz and Shahbaz, 2021). The intention of farmers to embrace CSA practices is influenced by experience, socioeconomic factors, intuitive support, infrastructure, and solid policies (Ruben *et al*., 2019). The advantage of CSA measures has a direct positive implication on farmers' income improvement and mitigate the negative impact of climate change and related risks (Hussain *et al*., 2022). Farmers' response to adopt CSA practices tends to reduce climate risk, increase crop yield, improve household income, and meet the demand for farmers' food consumption (Ogunyiola *et al*., 2022).

In contrast, if farmers fail to adopt CSA measures and follow conventional farming, it may have consequences of increasing climate risk vulnerability and a reduction in crop yield production per hectare (Sardar *et al*., 2021). Smallholder farmers can reduce climate-related loss and damage through the adoption of CSA measures in their farming system (Musafiri *et al*., 2022). Smallholder agricultural productivity and crop income eventually increase household food security, and CSA interventions improve farm revenue and food self-sufficiency (Sedebo *et al*., 2022). The conceptual framework of this study links climate change and variability to farmers' understanding and awareness of climate change, factors that influence the implementation of CSA, and its impact on household income and food security.

3.6. Methodology

This section provides a detailed overview of the study methodology used for this study. It covers the process of selecting the study area, gathering samples, selecting households, and collecting and analysing data.

3.6.1. Research design

The study focused on smallholder farmers in the ‘Southern Nations, Nationalities, and Peoples Region (SNNPR) of Ethiopia’, specifically in districts where climate smart agriculture practices have been introducing since 2012. A method of multistage sampling was used to select the study site and households for the sample selection. In the beginning stage, Doyogena district from the Southern region in which CSA practices have been tested and promoted for a decade was randomly selected. In the second stage, two *Kebeles* (the lowest level administrative units of the ‘Federal Democratic Republic of Ethiopia)’, were randomly selected. In the third stage, with the help of extension personnel and peasant associations leaders, four villages from each Kebeles in total 8 villages from two kebeles were identified, and a total of 385 survey participants were randomly selected for the final survey interview. A combination of both quantitative and qualitative data was employed in a research design to gather information from primary and secondary sources.

This approach was used to examine how farmers' understanding, and perceptions of climate change contributed to the adoption of CSA measures as an adaptation strategy, as well as to determine whether CSA practices improved farmers income and food security. The national meteorology agency provided meteorological data. Semi-structured questionnaires were used to perform a cross-sectional household survey. The objective of the survey was to gather important data about farmers' understanding of climate change and their adoption of CSA measures. The study employed qualitative techniques to collect data, such as conducting 'Focus Group Discussions (FGDs), Key Informant Interviews (KIIs)', and direct observations. The necessary secondary data was obtained by conducting a review of relevant literature pertaining to climate, crops, livestock, and other socioeconomic factors.

3.6.2. Analysis of trends and variability of rainfall and temperature

This section discusses data collection activities such as desktop studies, field work studies, and data analytical procedures for specific objective one.

3.6.2.1. Desktop studies

The 'National Meteorological Agency (NMA)' provides rainfall and temperature time series data from 1983 to 2016. In this work, 34 years of meteorological data is used to investigate the observed changes of rainfall and temperature across the given area. Annual rainfall and temperature data from each station were calculated by combining and averaging the station data (Tabel 3.1) from 1983-2016 (Gissila *et al*., 2004; Cheung *et al*., 2008).

Table 3.1: The name, altitude, coordinates, and years of the selected meteorological stations

Name of station	Lat. (N)	Long. (E)	Alt. (a.m.s.l)	Duration
Doyogena	7° 20'	37° 47'	2629	1983-2016
Angacha	7° 20'	37° 51'	2321	1983-2016
Durame	7° 14'	37° 53'	2116	1983-2016
Alaba Kulito	7° 31'	38° 09'	1726	1983-2016
Hossana	7° 34'	37° 51'	2306	1983-2016
Fonko	7° 38'	37° 58'	2246	1983-2016

3.6.2.2. Fieldwork Studies

Local meteorological stations in the study area were identified and chosen for analysis. The weather stations were chosen based on the relative completeness of data availability and the length of years that fulfills the requirements of the World Metrological Organization (WMO) typically three decades or longer. It is standard procedure to undertake climatological research with a minimum of 30 years of data (Wodaje *et al*., 2016).

3.6.2.3. Data Analysis

The analysis of climate data is conducted at different scales, including monthly, yearly, and seasonal. The analysis of temperature time series involved calculating annual and seasonal averages based on monthly climatic data. The analysis of rainfall time series involved using annual and seasonal totals. In this study, different statistical techniques are employed to analyze long-term climate variability and trends over the study area. For example, there are several methods used to assess rainfall patterns such as the ‘Standardized Rainfall Anomaly (SRA), Standard Precipitation Index (SPI) and Standard Anomaly Index (SAI). A standard rainfall anomaly is a more general term for the deviation of observed rainfall from expected values, while SPI is a specific index standardized for measuring precipitation anomalies over various time scales. Additionally, SAI may include a variety of indices used to measure anomalies in environmental variables, including precipitation, which may or may not adhere to SPI's standardization.

Whereas ‘the coefficient of variation (CV) is used to analyse the seasonal and annual variation of precipitation patterns (Svoboda *et al*., 2012; Hänsel *et al*., 2016; Asfaw *et al*., 2018; Esayas *et al*., 2019)’. Two non-parametric statistics are used in this study: Sen's Slope is used to identify trend magnitude, and ‘Mann-Kendall (MK)’ is used to determine trend direction. Sen's Slope is commonly used to determine the percentage shift in the variable over the studied timeframe’. The ‘Standard Anomaly Index (SAI) is used for the calculation of rainfall patterns to identify extreme wet and dry periods (Agnew *et al*., 1999; Babatolu *et al.*, 2013; Gleixner *et al.*, 2017; Koudahe *et al.*, 2017; Asfaw *et al.*, 2018).

The SAI index is calculated as shown in Equation (3):

$$Z = \frac{(X_i - \overline{X_i})}{S} \quad (3)$$

Where the standardized rainfall anomaly, denoted as Z, is calculated using the annual rainfall values, represented by xi, based on the historical record. The value (xi)¯represents the average annual rainfall, while **s** indicates the variability of the annual rainfall based on historical observations of the time series.

Extreme drought conditions are classified as such (Z -1.65), severe (-1.28 > Z > -1.65), and moderate (Z > -0.84) (Agnew *et al*.,1999; McKee., 1993; Viste *et al*., 2013). Extreme drought and an extreme rainy year are indicated by the standardized rainfall anomaly index, which runs from ≤-2.0 (dry) to ≥ 2.0 (wet), respectively.

The degree of variability in seasonal and annual rainfall was measured using the Coefficient of Variation (CV). According to Hare (2003), there are three categories for rainfall variability: high (CV > 30), moderate (20 < CV > 30), and low (CV < 20).

The CV value is computed with the following (Equation 4):

$$CV = \frac{\sigma}{\mu} \times 100 \quad (4)$$

where σ is the standard deviation, CV is the coefficient of variation, and μ is the mean precipitation for the period of record.

The ‘Precipitation Concentration Index (PCI) is used to evaluate the monthly, seasonal, and annual rainfall distribution. According to De Luis *et al.* (2000) and Gocic *et al.* (2013), PCI is used to show the risk of floods and drought occurrences in the study area and computed in (Equation 5)’:

$$PCI = \frac{\sum_{i=1}^{12} p_i^2}{(\sum_{i=1}^{12} P_i)^2} \quad (5)$$

Where Pi is monthly precipitation in the month i, and Σ_i is summation of precipitation.

A PCI value of < 10 indicates that precipitation is distributed uniformly; PCI value ranging from 11-15 indicates moderate rainfall concentration; PCI a value between 16 and 20 indicates an erratic rainfall distribution, whereas a value more than 20 indicates a highly irregular rainfall distribution across the area (Oliver, 1980).

One of the most used methods for determining climate trends is the Mann- Kendall (MK) trend test. Mann and Kendall (1975) provide specifications for the MK test. The MK test is used to identify patterns in the annual and seasonal variations of climate parameters that are monotonically increasing or decreasing. To find out if there have been any changes in the temperature and rainfall indices over time, Sen's estimator and the MK trend test are used. Climate outliers have less of an impact on the MK test's ability to detect annual and seasonal trend changes (Birsan et al., 2005). The MK test is performed using monthly, seasonal, and yearly rainfall data from 1983 to 2016 in the study area. The Z value and trend are calculated using Sen's slope (β) estimation.

The MK Statistics(S) can be calculated with (Equation 6):

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(x_j - x_k) \quad (6)$$

‘Where x_k and x_j are the sequential data values of the time series' k and j (j > k), and n is the length of the time series. A positive S value shows an increasing trend in the provided time series data, whereas a negative value indicates a decreasing trend. The sign function is given (Equation 7)’:

$$Sgn(x_j - x_k) = \begin{cases} 1\ if(x_j - x_k) > 0 \\ 0\ if(x_j - x_k) = 0 \\ -1\ if(x_j - x_k) < 0 \end{cases} \quad (7)$$

The variables x_j and x_k represent the annual data values for a given set of years, k and j(j>k) respectively.

When the sample size or observation is less than 10 (n < 10), the S statistics follows an approximately standard normal distribution with a mean of zero. In this case, the variance of the statistics is estimated by (Equation 8).

$$\mathrm{Var(S)} = \frac{n(n-1)(2n+5) - \sum_{k-1}^{m} tk(tk-1)(2tk+5)}{18} \qquad (8)$$

Where 'Var(S) represents the variance of the quantity, n implies the number of observations, and m is the number of tied groups. Tied groups refer to sets of sample data with the same value, and it indicates the number of data points in ith group and tk represents the tied value of the ith sample time series. The MK test is used to determine if a time series is decreasing or increasing; in this case, the highest S positive values show an increasing trend, while the lowest S negative values indicate a decreasing trend. The Z statistics are calculated by (Equation 9)':

$$Z = \begin{cases} \dfrac{s-1}{var(s)} \; if \; s > 1 \\ 0 \; if \; s = 0 \\ \dfrac{s+1}{var(s)} \; if \; s < 0 \end{cases} \qquad (9)$$

The Z statistic measures the significant level of the trend i.e., positive, and 'negative Z value indicate upward and downward trends of the given period respectively. Z_0 is the null hypothesis which indicates trends are not observed and accepted if $|Z| \leq Z\ \alpha/2$, where $Z\ \alpha/2$ is the normal distribution. Hence, the climate data is statistically analyzed at a 95% confidence interval (alpha value of 0.05) for each time series data.

The time series data is analysed using the nonparametric tests donates as Sen's slope method (Sen, 1968) to determine the linear trends. The 'Sen's method calculates the magnitude of the Sen's slope in a sample of N data pairs. A positive value for β indicates a increasing trend, while a negative value indicates a declining trend in the time series. Hence Sen's slope (T_i) in any two values of N pair's data can be computed by (Equation 10)':

$$(T_i) = \frac{(xj - xk)}{j-k} \qquad (10)$$

Let xj and xk denote the data value at time j and k (where j>k) respectively. Sen's slope estimator is defined as the median of the N values of the Ti.

The most used technique for identifying and characterizing meteorological drought is the Standard Precipitation Index (SPI) (McKee *et al*., 1993; Karabulut, 2015). According to Svoboda *et al.* (2012), SPI can be computed for a range of time periods, including 1, 3, 6, 12, 24, and 48 months. Twelve-month or annual periods (SPI-12) are employed in this study. SPI value is calculated as (Equation 11):

$$SPI_{ij} = \frac{X_{ij} - \mu_{ij}}{\alpha_{ij}} \quad (11)$$

In the given equation (9), 'SPIij represents the rainfall total value for i^{th} month at j^{th} period, while xij represents the observed rainfall total value for i^{th} month at j^{th} period. The variables μij and αij represent the long-term mean and standard deviation of the selected period (i^{th} month at j^{th} time scale), respectively'. McKee *et al.* (1993) and Svoboda *et al*. (2012) indicate SPI has a range of output values from -2.0 to 2.0, as shown in Table 3.2'.

Table 3.2. Standard Precipitation indices and their interpretation

SPI Value	**Interpretation**
≥ 2.0	Extremely wet
1.5 to 1.99	Severely wet
1.0 to 1.49	Moderately wet
0.99 to -0.99	Near normal
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Severely dry
≤-2.0	Extremely dry

Source: Svoboda *et al*. (2012)

3.6.3. Investigating farmers' knowledge of climate change and adoption of climate-smart farming practices for climate change adaptation

This section presents data collection activities such as desktop studies, field work studies, and data analysis procedures for specific objective two.

3.6.3.1. Desktop Studies

The study involved collecting data from various sources such as published articles, working documents, policy briefs, and annual reports from NGOs, the ‘Ministry of Agriculture’, as well as offices for rural development. The research focuses on examining the understanding and attitudes of farmers towards climate change, alongside their implementation of CSA practices.

3.6.3.2. Fieldwork Studies

To gather the required information on the socioeconomic and demographic features of the households, a semi-structured survey questionnaire was designed. The study examines farmers' understanding of climate change, rainfall, and temperature variability. The farmers were polled on a broad range of topics, including how they felt about the changing climate and its variability. The responses were utilized to conduct a perception survey with the farmers. In the follow-up questions of the survey, respondents were asked to provide evidence of the changes that they have witnessed or experienced during the past three decades. In addition, the study measures farmers’ perception of climate change and variability using three key variables: rainfall and temperature changes and a general understanding of climate change.

Farmers were asked a general question about their feelings regarding changing climate and variability. The responses were used to measure the farmers’ perceptions. Information on farmers' understanding, the effect of climate-related risks on their livelihoods and natural resources, farming systems, farmland characteristics, training, credit services, climate information, and challenges with adaptation were among the topics covered by the questionnaire. Moreover, questions about farmers’ CSA practices and its influences on household income and food security were added while food consumption score was used as an indicator for household food security. The household interview and checklists were designed to gather qualitative information to supplement the household questionnaire survey. The survey was carried out between September 2020 and February 2021. Data collection took place during the COVID-19 epidemic, and it was challenging to conduct face-to-face interviews due to social distancing measures, and movement limitations.

Participants in the FGDs and KII included farmers, government, and NGO representatives, as well as heads of community members, Kebele administrations, and development agents. FGDs and KIIs helped to capture comprehensive information on farmers' knowledge and perception of precipitation and temperature patterns for the previous three decades, climate risks, perceived impacts of weather variations, and CSA adaptation measures toward climate change. The questionnaire and checklist were pretested before the actual data collection phase(Creswell, 2017). Following the pre-testing procedure, we conducted further modifications and corrections of the questionnaire and checklists.

Household survey: A survey was conducted in Doyogena district, Southern Ethiopia to gather data on the knowledge and perceptions of climate change and the use of CSA measure among farmers. The survey conducted interviews with a total of 385 households. Since Ethiopia has not conducted an official census since 2007, it is uncertain how many people reside at the research location. To determine sample households for the interview, locally estimated total population and number of households were acquired from district agriculture and rural development office and InterAide project office. A total of 385 households, 80.5% male and 19.5% female respondents, were selected from 10267 sampled population using Yamane (1967) formula proportionally and figured as follows (Equation 12).

$$n = \frac{N}{1 + N(e)^2} = \frac{10267}{1 + 10267(0.05)^2} = 385 \ \ households \qquad (12)$$

Where: *n* indicates the sampled households for the study *N* = total number of households in the district and e is the level of precision (5%).

To properly identify the study site and households, the study used a multistage sample strategy that included a combination of sampling procedures. In the beginning step, a district from the Southern region was selected randomly in which CSA practices have been tested and promoted for a decade. In the second step, two *Kebeles* (the lowest level administrative subdivisions of Ethiopia's federal democratic republic) were chosen at random. In the third stage, with the help of extension personnel and peasant association leaders,4 villages from each Kebeles in total 8 villages were identified, and 385 households were randomly selected for the final interview (see equation 10).

The study used mixed research designs, gathering data for both quantitative and qualitative analysis from primary and secondary sources (Section 3.6.3.2). A detailed distribution of sample households in the area is provided (Appendix ‘A’).

Focus Group Discussion (FGD): FGD were held with the selected group of individuals to get their thoughts and opinion on the topics of the research questions (Appendix B). FGDs participants were selected purposively using the following criteria: Farmers who have lived in the study site for a longer period (not less than 20 years) and who have firsthand information or experience of the local environment, historical and current weather conditions. Participants were selected with the help of local development agents, kebele administrations and district agriculture and rural development experts. A mixed focus group discussion was conducted for each study kebele, with a total of 12 participants (8 men and 4 women). A total of 24 participants, consisting of 16 men and 8 women, participated in the FGDs in the two kebeles. The FGDs lasted for two hours each, with language translation took longer because participants did not speak Amharic and English. Participants were asked about their views, knowledge, attitudes, and beliefs regarding previous and current climatic variations, climate-related consequences on their farming activities, and adoption of CSA practices as an adaptation measure.

Key informant interviews: The KIIs were conducted in February 2021 using a checklist of open-ended questions. The place of the interview was chosen by the key informants in their villages. The average time for the face-to-face interview with a key informant lasts between 20 and 30 minutes. The interviews were conducted with 16 individuals, and the key informants are a more homogeneous group, therefore 16 people were adequate numbers for this study. The interviewees were selected from several groups, including model farmers (8), district development agents, and agricultural professionals. (2), *Kebele* administrators (2),’ non-governmental organizations in the district (2) who provide agricultural extension services to farmers, and leaders of community-based organizations (2) individuals with experience on climate change and adaptation’ (Appendix C).

The following criteria were used to choose the key informants: Farmers who have lived in a specific place for a longer period (at least 20 years); or who have direct knowledge or experience with the local environment, weather patterns, climate change, and agricultural practices.

The procedure for choosing informants was carried out with the assistance of the kebele administration, development agents, and experts in district agriculture and development. During data collection, factors including a farmer's age, education status, farming experience, and farmers knowledge of climate change have been examined. Due to their hesitation, voice recording was not possible during the KII; instead, notes were taken. During the field work, different kinds of CSA practices were identified and relevant information from households was collected (Appendix D).

3.6.3.3. Data Analysis

Descriptive statistics were employed to analyze household characteristics, socioeconomic issues, and farmers' awareness about climate change and its related impacts. The Heckman sample selection model was used to determine the factors influencing the perceptions of farmers and implementation of CSA measures (Deressa *et al*., 2011). STATA software version 14.2 was used to enter, code, and process the gathered data. The dependent variables used for the selection model are farmers' perception to climate change, which includes rainfall and temperature variations and adaptation measures taken. The dependent variable in the outcome model is farmers adaptation to CC through the adoption of CSA. The models employed in recent studies on farmers' knowledge and perceptions of climate change and adaptation measures include independent variables such as socioeconomic, demographic, environmental, and institutional aspects. In addition, the relationship between the variables was determined using the chi-square test.

Qualitative data collected from smallholder participation in KIIs, and direct observations were analyzed using narrative analysis methods. Perception research on climate change and variability employ several models, such as nominal or ordinal probit models and binomial probit models(Maddison, 2006; Piya *et al*., 2012), 'multivariate discrete choice model (Nhemachena and Hassan, 2007), Heckman probit selection model (Deressa *et al*., 2011), binary probit model (Khan *et al*., 2021), binary logit model (Onyeneke *et al*., 2018), and ordinary least square estimation (Huong *et al*., 2017; Uddin *et al*., 2017; Marie *et al*., 2020; Nyang'au *et al*., 2021; Sertse *et al*., 2021)'.

However, in this type of survey-based empirical research, there is a significant issue that can lead to a biased causal effect of the measured variables on the outcome variables being studied (Wooldridge, 2016; Wuepper *et al*., 2018). Recent studies, particularly those on climate change perception, attitudes, behavior, knowledge, and choices, face biased estimate caused by omitted variables (Mehiriz and Gosselin, 2021; Sajons, 2020). To overcome this biased causal effect, the Heckman probit selection model was used to assess farmers' knowledge of climate change and efforts to apply adaptation strategies. This model enables obtaining reliable and accurate estimations for each of the model's parameters.

The process of climate change adaptation involves a two-step procedure. First, there is a need to recognize the changing climate. Then, in the second step, it is critical to be prepared to put adaptation measures in place (Morton 2007; Deressa *et al.*, 2011). To address this selection bias, the two-step maximum likelihood procedure was employed (Heckman, 1976). Heckman's selection model examines how farmers' understanding, and views of climate change influence their decision-making process. It also explores how these factors impact the actions farmers take to adapt to climate change. Heckman's probit selection model necessitates the existence of an underlying relationship, which is represented by (Equation11):

$$y_j = x_j\beta + \mu 1_j \qquad (11)$$

Where x represents a vector of explanatory variables that impact adaptation measures, yj denotes the latent variable, or the tendency to adopt climate change measures, β represents the estimated parameter, and μ1j represents the error term. The probit model only displays the binary result in this case (Equation 12):

$$y_j^{probit} = (y_j > 0) \qquad (12)$$

In the selection equation (Equation 13), the observation of the dependent variable is conditional on the observation of j:

$$y_j^{select} = (z_j\delta + u2_j > 0) \qquad (13)$$

$\mu 1 \sim N(0,1)$, $\mu 2 \sim N(0,1)$; Corr $(\mu 1, \mu 2) = \rho$

Where z is the vector of explanatory variables that influence farmers' perception of climate change, δ is the parameter estimate, and μ1 and μ2 are the error terms, which are normally distributed with mean zero and variance one and y_j^{select} indicates whether the farmers observed climate change.

In this case, the initial step of Heckman's two-stage model centers around the selection model (Equation 11), which encompasses farmers' perception of climate change. In the next step, I focus on the outcome model (Equation 12). This model illustrates how farmers decide to adopt climate change adaptation measures, considering their perception of climate change. When there is correlation between the error terms in the selection and outcome model, or when $\rho \neq 0$, the estimates obtained from the standard probit model applied to (Equation 12) may be biased. Therefore, the Heckman probit model is a valuable tool for obtaining accurate and reliable estimates for all parameters in the model (Van de Ven and Van Praag, 1981). As a result, the Heckman probit selection model is used in this study to investigate farmers' understanding of climate change and adaptation measures in southern Ethiopia. The selection of explanatory variables that may affect farmers' understanding of climate change and adaptation measures is made based on available literature (Appendix ‘E’).

The model variables that were chosen based on available literature are indicated in Appendix E. shows. Climate perception related variables have been measured in previous studies using either a Likert scale (Nuamah and Botchway, 2019; Behailu *et al.*, 2021; Jellason *et al.*, 2021; Sertse *et al.*, 2021) or by treating perception as a dummy variable (Roco *et al.*, 2014; Makate *et al.*, 2019; Marie *et al.*, 2020; Nyang'au *et al.*, 2021). Perception is assessed using a multi-step process. During the initial phase, prepared open-ended questions were posed to the farmers (e.g., “Do you know what climate change is? Have you perceived any change in climatic conditions in the recent past in your local area? Which climate factor/s did you perceive as a change? What changes have you observed concerning the factors you have perceived in the last three decades?”). Depending on the answers provided to the first two questions, the farmer is considered to (not) “perceive” climate change in their area. In the second stage, a farmer’s perception was treated as a dummy variable that takes the value of 1 if the farmer perceives that the climate is changing, and 0 if not. A series of questions were asked to the farmers to define the variable CSA adoptions (Appendix ‘E’).

3.6.4. Examining the impacts of CSA on household income and food security.

This section discusses data collection activities such as desktop studies, field work studies, and data analysis procedures for specific objective three.

3.6.4.1. Desktop Studies

This research carried out a comprehensive review of scientific sources pertaining to CSA practices and their potential implication on income and food security. The review was conducted by analyzing a diverse range of sources, including published articles, working papers, and policy documents. This was complimented by the field studies described below.

3.6.4.2. Fieldwork Studies

The main data collection tools used for this objective include household questionnaire interview, FGD and KIIs. Data was collected from 385 households as was presented under Section 3.6.3.2 through semi-structured household interviews to investigate the effect of CSA measures on farmers benefits such as income and food security. This study involved conducting FGD and KII in selected villages to examine the impact of climate change on agriculture and adopting CSA practices as a means of adaptation. The study conducted an analysis on the impacts of CSA implementation on both income and food security. FGD and KII were designed to collect information on farmers' understanding of rainfall and temperature variations, implementation of CSA measures as a climate change adaptation strategy, the impact of CSA practices on soil fertility improvement, crop income, and household food consumption. The information contained in the data collected from primary and secondary sources included socioeconomic characteristics of farmers' income sources. Farmers' income data were gathered using the expenditure method that is less sensitive to measurement than direct annual estimation (Angus, 1997; Battistin, 2003; Kanu and Okezie, 2021).

Household food security: The nutrient adequacy of the households was determined using the most prevalent proxy tools, namely the Food Consumption Score (FCS). Each target household's food consumption history (type and frequency of each food consumed) is categorized into nine food groups (i.e., main staples, pulses and nuts, vegetables, fruits, meat and fish, dairy products, sugar, oil, and other condiments) with a 7-day recall from the date of survey data collection. The frequency of each food category is weighted by the World Food Program's (WFP) specific values and summed to provide an individual FCS that can be compared to standardized cut-off points (WFP-VAM, 2008). Standard cutoff points were utilized to classify the sample household based on its level of nutrient sufficiency (Appendix F). Along with the survey interview, FGDs and KIIs were conducted to validate the results from the household interview (Section **3.6.3.2**). The field work was conducted from September 2020 to March 2021.

3.6.4.3. Data Analysis

Income and food security were used to assess the impact of CSA measures. The income of the household came from both on-farm (crop-livestock) and off-farm sources, including as remittances, self-employment income, and non-agricultural wages (Bojnec and Knific, 2021). Food security refers to the state in which every member of a household has consistent access to an adequate supply of safe and nutritious food that fulfills their dietary requirements (FAO, 2009; Tendall *et al*., 2015). The World Food Program (WFP) commonly uses FCS to measure the quantity of food groups consumed in a family over a specific reference period (Mujeyi *et al*., 2021). It is computed based on the frequency of weighted dietary diversity of households consuming nine food groups (Section 3.7.1.2). The consumption frequency is then summed to give the food group score, and each group score was multiplied by the weights of each nutrient density of the given food groups (see, Appendix F) to yield the FCS (Carletto *et al*., 2013; Maxwell *et al*., 2014) as shown below (Equation 14):

$$\text{FCS} = \sum yifi \qquad (14)$$

Where FCS is Food Consumption Score, yi represents different food groups, i is the weight of the nutritional value of each food group, and fi is the consumption frequency of food groups that the households consumed within the last 7 days. Adopting CSA options helps farmers increase food supply availability and generates more income. Smallholder farmers decide to adopt a new framing strategy in this process and estimating the impact of such adoption intervention is critical (DiPrete and Gangl, 2004).

This study utilized the 'Propensity Score Matching (PSM)' approach to measure the effects of CSA adoption on household revenue and food security outcome indicators (Khonje *et al*., 2015; Brüssow *et al*., 2017). PSM estimation is a valuable tool for examining the impact of CSA measures on household welfare. It allows us to explore this effect by assuming that unobserved factors do not have an influence on CSA adoption, and that there is considerable propensity score overlap between individuals who use CSA and those who do not (Maina *et al*., 2019).

In pre-treatment observable characteristics, the PSM approach is used to find a similar group of farmers who have adopted the available CSA options and compare them to other similar farmers who have not adopted any CSA options. After controlling the pre-treatment observable characteristics associated with CSA adoption, we confirmed that adopters and non-adopters have outcomes comparable to what those who did not adopt CSA would have experienced. The outcome variables (food security or household income growth) of individual farmers who engaged in CSA practices (y_1) are compared with that of similar farmers who did not participate in CSA adoptions (y_0), this is the foundation for the Average Treatment Effect (ATE). The average gain from the result of program participants (treatment group) versus non-participants (control group) can be introduced (Equation15):

$$ATE=E(Y_i (1) |T_i =1)-E(Y_i(0)T_i=1) \qquad (15)$$

Where Y_i is the outcome for individual i, Ti is the treatment dummy variable, Y_i (1) represents an outcome of individual under treatment, and Y_i (0) is an outcome of an individual who is a non-participant. PSM constructs the statistical comparison group based on the likelihoods of participating in the treatment (in our case, adoption of CSA practices), conditional on variables (covariates) that are thought to affect treatment participation and can be expressed (Equation 16):

$$P(X)= Pr(T=1 |X) \qquad (16)$$

Food security and gross household income are the study's outcome variables, which measures the effects of CSA adoptions. The outcome of farmers who adopted CSA practices(adoption of any CSA practices, an index generated from a set of practices) in response to the perceived effects of climate change is contrasted with those farmers who did not implement any CSA measures; these two groups are assumed to not be different systematically besides CSA adoption. In this regard, the average treatment effect on the treated (ATT) and untreated (ATU) assesses the differences in treatment and control group outcomes (food security or household income) after matching. As a result, the ATT is the difference between with and without treatment, as calculated by (Equation 17).

$$ATT = E\,(Y1|T = 1) =+E\,[(Y1|T = 1)] - E\,[Y\,(0)\,T = 1] \tag{17}$$

Two presumptions, that is, common support condition and conditional independence, underlie the validity and satisfaction of the PSM estimation outputs (Rosenbaum and Rubin, 1983). The conditional independence or unconfoundedness assumption states that the potential outcome is independent of treatment status and used to establish an unbiased counterfactual for the treatment group after controlling the set of Xi observable covariates (Wake *et al*., 2019).

The equation can be expressed as: $(YiT, YiC) \perp Ti|Xi^*$ (18)

Then, we obtain (Equation 19)

$$Yi\,(1) = YiT \text{ and } Yi\,(0) = YiC \tag{19}$$

Where YiT is the outcome of an individual on treatment, YiC is the outcome of an individual on control, Xi* is the covariate, and $\perp$ is the independence. Meanwhile, the assumption of common support certifies that as overlapping between treated and untreated groups is sufficient, acceptable matches can be obtained. The equation is given as $0 < P\,(T = 1|X) < 1$.l

It guarantees that the comparison observation is close to the treatment observation in the propensity score distribution. According to Rosenbaum and Rubin (1983), the treatment assignment is intended to be strongly ignorable if the presumptions are true. In general, PSM estimation consists of two steps, both of which are used in this analysis. The first stage is based on the entire sample, and a binary outcome model with a binary treatment variable is used, which is a probability conditional on the characteristics of the households. This stage helps in reducing section bias by employing a matching algorithm as a robustness check (Caliendo and Kopeinig, 2008).

Considering the observable characteristics X, the PSM technique is used to evaluate the chance that farmers engaged in CSA practices. The propensity score P(X) is then calculated by constructing comparison matching groups with comparable propensity scores, and unmatched units are removed from the model (Caliendo *and* Kopeinig, 2008).

The analysis includes the use of various matching algorithms commonly employed in propensity score matching (PSM) estimation. These algorithms include 'Nearest Neighbor Matching (NNM), Kernel-Based Matching (KBM), Radius Matching (RM), and Caliper Matching (CM)'. In the second stage of PSM, the impacts of CSA adoption on the average outcome variables (food security and income) are determined, and the ATT is estimated. The NNM method is used to pair participant households with nonparticipant households based on their propensity score distance. However, the NNM faces bad matches if the propensity score distance between two neighbors is large. This can be avoided by imposing a tolerance level on the maximum propensity score, and caliper matching with 0.1 restrictions is specified for common support conditions (Smith and Todd, 2005).

The kernel matching method constructs the counterfactual outcome and produces the average treatment effect on the treated using the kernel weighted average of the farmers in the adopter group. The key capability of PSM estimation is controlling selection bias, which is dependent on two conditions: the balancing performance of the given covariates and the absence of systematic household heterogeneity due to the household's unobserved characteristics (Caliendo and Kopeinig, 2008). The balancing test in PSM estimation assumes that it will balance the variable distribution, reduce bias, and eliminate potential differences in the given covariates (Rosenbaum and Rubin, 1983). Moreover, the PSM addresses the systematic difference due to observable characteristics among households in two ways: first, by estimating the probability of propensity score for each observed characteristic using the logit or probit model, and second, by matching each adopter with non-adopters who have the same propensity score value to estimate the ATT. The matching approach is the widely used method to estimate ATEs (Karimi *et al*., 2020). The estimation of the ATE using various matching algorithms is not robust against hidden bias.

Hidden bias characteristics, such as unobserved factors, are believed to have the potential to influence the estimation of matching for treatment and outcome variables (Becker & Caliendo, 2007; Rosenbaum, 2002). Rosenbaum's (2002) proposed abounding approach is used to address such hidden bias. The outcome variable calculated at various gamma critical level values suggests that the p critical levels are significant, implying that the important covariates which can affect both CSA adoption and outcome variables, have been considered in this study. I did not find the critical value of gamma* that questioned the estimated value of ATT (Annex 1). Based on the bounds estimation, it can be concluded that the results of average treatment effects (ATEs) are not influenced by the presence of hidden bias. Implementing CSA practices has an important effect on the financial well-being of households and their ability to access food. Thus, it is crucial to consider the potential bias caused by unobserved selection variables when estimating the impact of adopting CSA practices.

In addition, the Heckman selection model is employed to resolve the possible correlation between observed covariates and selection bias (Asrat and Simane, 2017). Furthermore, the Rosenbaum bound test is conducted to address unobservable hidden bias (Rosenbaum, 2002; Heckman and Navarro-Lozano, 2004). The testing approach includes adjusting the significance level bound at the ATT under the provided assumption of self-selection into CSA adoption, hence identifying the level of ATT estimation at which the significance level became insignificant (Caliendo and Kopeinig, 2008). Following Sardar *et al.* (2021) average treatment effects are examined by comparing the projected crop revenue and FCS of CSA adopters and non-adopters (i.e., counterfactual outcomes).

CHAPTER FOUR: RESULTS AND DISCUSSION ON CLIMATE VARIABILITY AND TRENDS IN SOUTHERN ETHIOPIA

4.1. Introduction

This chapter summarizes the findings and discussions for specific objective 1. The chapter covers monthly and seasonal rainfall patterns as well as temperature trends reported in the study area over a three-decade period. Furthermore, the chapters discuss the key findings before presenting the summary and conclusion.

4.2. Results obtained for Objective One

These are presented in the sections below.

4.2.1. Rainfall Summary Statistics

An overview of the rainfall data for the study area from 1983 to 2016 is shown in Table 4.1. Important statistical measures conducted including the mean, standard deviation (SD), rainfall contribution, and coefficient of variation '(CV) are included in the Table 4.1. As shown, the mean annual precipitation was 1023.24 mm, with a standard deviation of 142.60 mm. August and July are the two months that experience the highest monthly rainfall. In August, the rainfall reaches 162.57mm, while in July it is slightly lower at 160.74mm. These two months contribute significantly to the overall annual rainfall, with August accounting for 15.89% and July contributing 15.71%. December and February had the lowest amounts of rainfall, which accounts for about 1.34 % and 1.47% of the total annual rainfall, respectively. The rainy season, or *Kiremt*, which runs from June to September (55.4%), and the planting season, or *Belg'*, which goes from late February to May (33.20%), account for most of the annual precipitation. During the dry season (*Bega*), which spans from October to February, there was a low amount of rainfall, which accounted about 11.35%.

Table 4.1: Summary statistics and MK trend test result (1983-2016)

Variables	Mean(mm)	SD(mm)	CV (%)	Sen.'s (β)	MK test (P-value)	Rainfall Contribution	Trends
January	15.02	16.53	110.04	-0.026	0.667	1.47	D
February	27.51	31.26	113.66	-0.720	**0.01***	2.69	D
March	69.27	40.42	58.35	-0.838	0.346	6.77	D
April	115.97	49.91	43.04	-0.304	0.659	11.33	D
May	126.97	50.33	39.64	-0.129	0.859	12.41	D
Jun	109.79	32.05	29.19	0.807	0.215	10.73	I
July	160.74	31.11	19.35	0.406	0.289	15.71	I
August	162.57	30.33	18.66	0.000	1.000	15.89	I
September	134.26	28.15	20.97	0.844	**0.054****	13.12	I
October	66.30	53.16	80.19	-0.080	0.977	6.48	D
November	21.18	25.58	120.78	0.595	**0.015*****	2.06	I
December	13.67	23.78	173.97	-0.046	0.532	1.34	D
Belg	339.72	97.00	28.55	-1.843	**0.027****	33.20	D
Kiremt	567.36	78.99	13.92	2.220	0.156	55.45	I
Bega	116.17	69.75	60.04	0.680	0.444	11.35	I
Annual	**1023.24**	**142.0**	**13.94**	**1.136**	**0.702**	**100.00**	**I**

Note: *, **, *** significant at 0.1, 0.5, 0.01 level; I= Increasing trend; D=decreasing trend

4.2.2. Linear Trend Analysis of Annual and Seasonal Rainfall

The MK test shows significant increasing trend in rainfall over the study area for the months of September ($p < 0.05$) and November ($p <0.05$) and a significant downward trend for February ($p < 0.01$). (Table 4.1) The rainfall trends showed an upward trend during June and July, while it experienced a slight decrease during March, April, and May. Based on monthly shares of rainfall, 57.51% shows a positive trend and 42.49% shows a negative trend. In the case of the *Belg* season (March to May), it exhibited a significant decline of 5% and the data indicates a low variation in annual rainfall of 0.474 mm/year. Furthermore, the analysis reveals that there are no significant trends of annual rainfall. Figure 4.1 depicts the seasonal trend analysis. The seasonal rainfall variability was recorded as -1.935mm/year, 1.841mm/year, and 0.568mm/year for *Belg*, Kiremt, and the *Bega*, respectively, whereas the declining trend of the Belg season was statistically significant (Table 4.1). As it is depicted in Figure 4.1, *Belg* rainfall has shown a decreasing trend and is significant at the $p<0.05$ level. The *Belg* season is important for farmers in most of the region since it affects their planting and preparation activities in a specific study area.

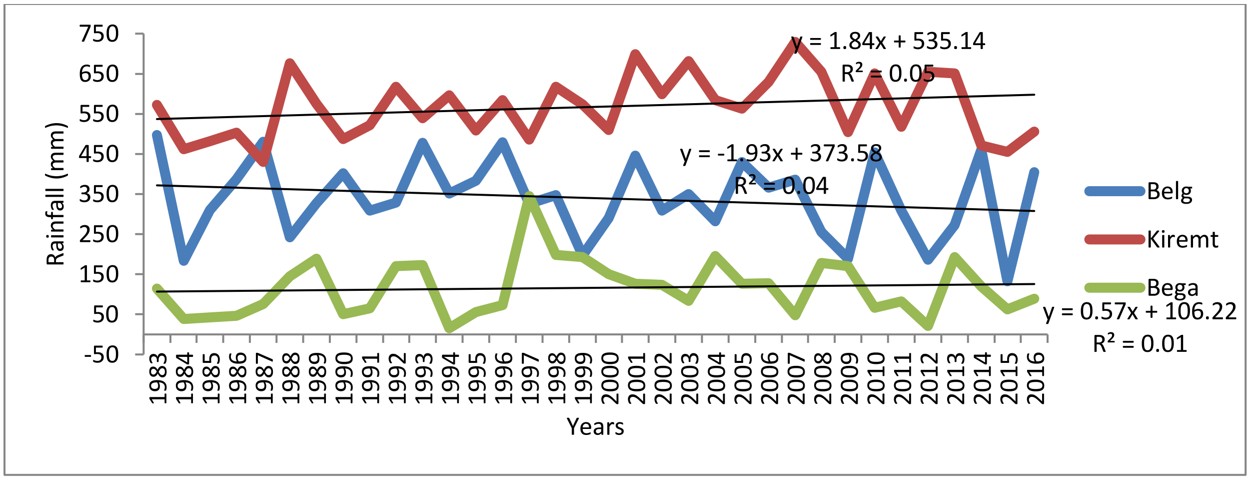


Figure 4.1: Seasonal rainfall trends over the observed period for 1983-2016

The annual trend was examined using linear regression, and the results are shown in Table 4.2. The result indicated that there was a 5% level of significant variation in rainfall distribution among seasons and annual observations from 1983–2016. However, the distribution of annual rainfall revealed a non-significant increasing trend, and the average rate of change of the rainfall variation was calculated as 0.47 mm/year (Table 4.2).

Table 4.2: Precipitation changes on an annual and seasonal basis (1983-2016)

Season	**Change in fall/mm/year**	**P-value**	**R^2**	**Mean(mm)**	**CV**	**% of annual rainfall**
Kiremt	1.841	0.156	0.054	567.36	13.92	55.45
Belg	-1.935	0.027	0.039	339.72	28.55	33.20
Bega	0.568	0.444	0.006	116.17	60.04	11.35
Annual	0.474	0.702	0.001	1023.24	13.94	100

A thorough analysis was performed on the annual mean rainfall data spanning from 1983 to 2016, divided into ten-year intervals. The average rainfall amounts for the periods 1984-1994, 1995-2005, and 2006-2016 are 972.59 mm, 1082.39 mm, and 1021.53 mm, respectively (Figure 4.2).

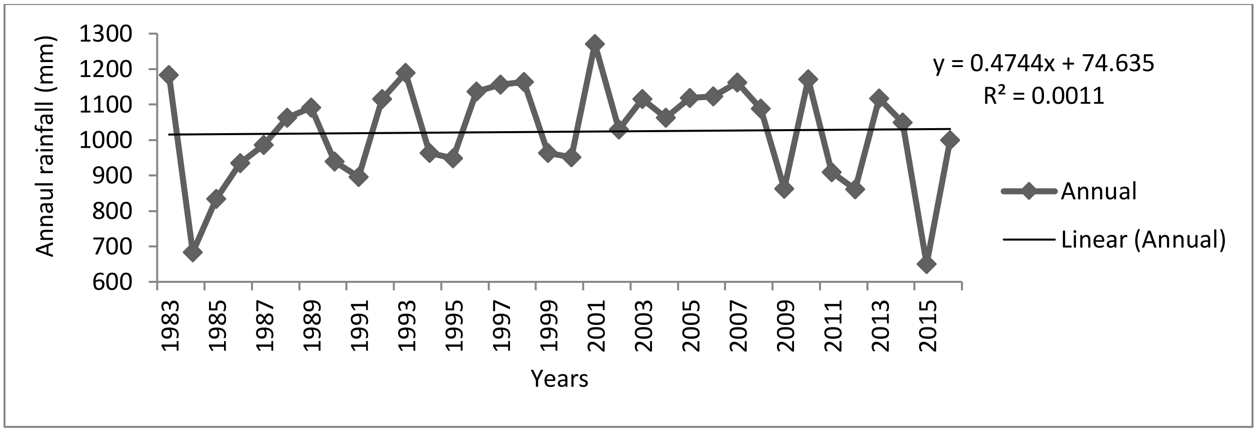


Figure 4.2: Annual trend of rainfall between 1983-2016

The primary rainy season, referred to as *Kiremt* (summer), begins in June and continues until September, while the second rainy season, known as *Belg* (spring), starts in February and extends until May. Figure 4.3 illustrates the findings with regards to the monthly anomalies.

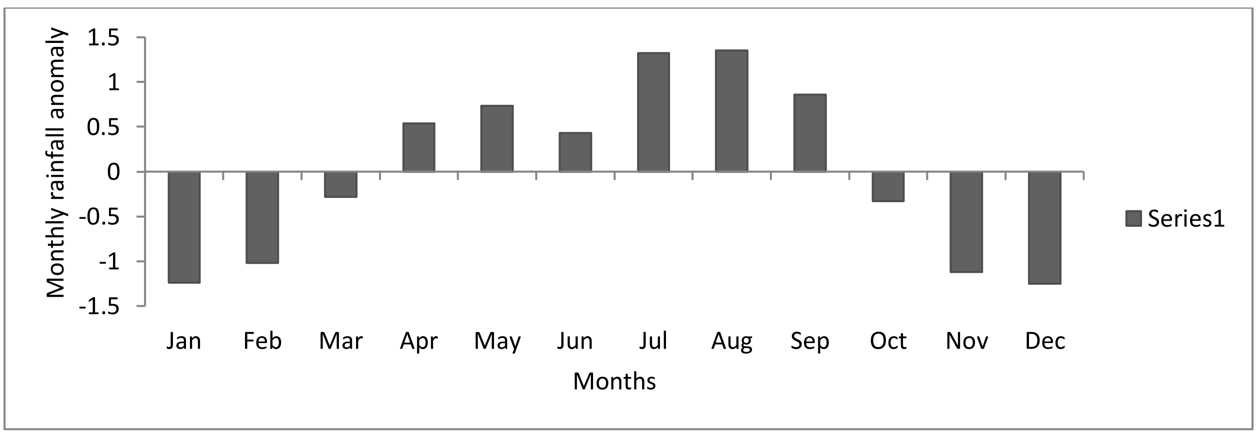


Figure 4.3: Standardized rainfall anomalies for monthly means (1983-2016)

4.2.3. Rainfall Variability

The seasonal rainfall data indicate a considerable variation in rainfall during the Bega season, with a high fluctuation of 60.04%. In contrast, the Belgian season showed moderate fluctuation of 28.55%. Annual rainfall, on the other hand, had a lower coefficient of variation, indicating that interannual rainfall variability (13.94%) was seen in the study area between 1983 and 2016. The year 2001 saw the highest positive anomaly at +1.74, while the year 2015 experienced the highest negative anomaly at -2.62. Figure 4.4 shows the annual rainfall anomalies from 1983-2016 in the study area.

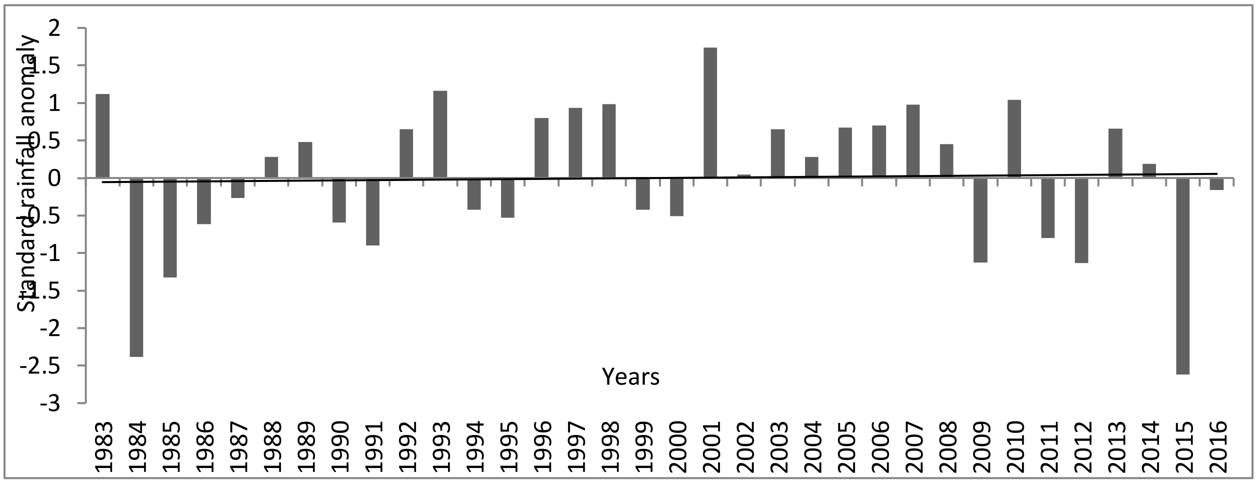


Figure 4.4: Standard annual rainfall anomalies of the study area (1983-2016)

Based on the computed annual rainfall anomalies, drought years are identified for the study area. 1984–7, 1990–1, 1994, 1997–2000, 2009, 2011, 2012, 2015–6 and most of these coincide with an El Niño event. As presented in Table 4.3, about 94% of the observed period experienced moderate rainfall distribution and about 6% of the rainfall distribution was irregular patterns. The 'Precipitation Concentration Index (PCI)' was calculated using a distinct class of PCI to measure the seasonal and annual rainfall distribution over the study period (Table 4.3). The study area experienced a moderate rainfall distribution according to the annual mean precipitation concentration index. The dry season, on the other hand, had an irregular rainfall distribution compared to the wet seasons.

Table 4.3: Years of the different PCI class in the study area (1984-2016)

PCI	**Categories**	**Years**	**Percentage**	**Seasons**
<10	Uniform rainfall distribution	0	0	Kiremt (PCI=8.76)
Between 10 and 15	Moderate rainfall distribution	32	94	Belg (PCI=12.09), Annual (PCI=13.17)
Between 16 and 20	An irregular rainfall distribution	2(1984, 2012)	6	Bega (PCI=17.09)
>20	Strong erratic rainfall distribution	0	0	

4.2.4. Trends of Drought

The results of the SPI values for the study area are presented in Figure 4.5. During the study period, the area had a range of precipitation levels, from wet to extremely dry years, as shown in Table 3.2. The year 2001 was wet; 1983, 1993, and 2011 moderately wet; 1985, 2009, and 2012 moderately dry; and 1984 and 2015 extremely dry. The rest of the year exhibited below normal rainfall distribution.

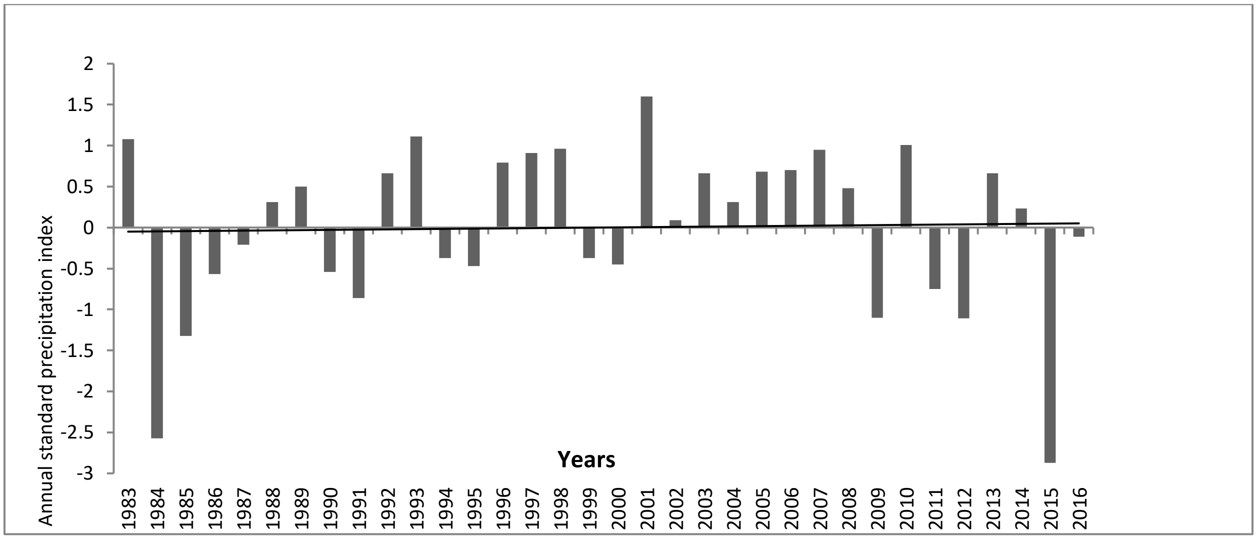


Figure 4.5: Standard Precipitation Index (SPI) for Annual rainfall series (1984-2016)

Figure 4.6 depicts the monthly SPI results. The study area experienced wet and drought months as indicated by the SPI-1-month value. This value serves as an indicator of the variability in rainfall distribution across the study area. The driest months were observed in March 2000, April 1984/2015, May 1989, June 1995/2015, July 1987, and August 1986. On the other hand, the wettest months were February 1990, August 2010, November 1997/2008, and December 1989/2002.

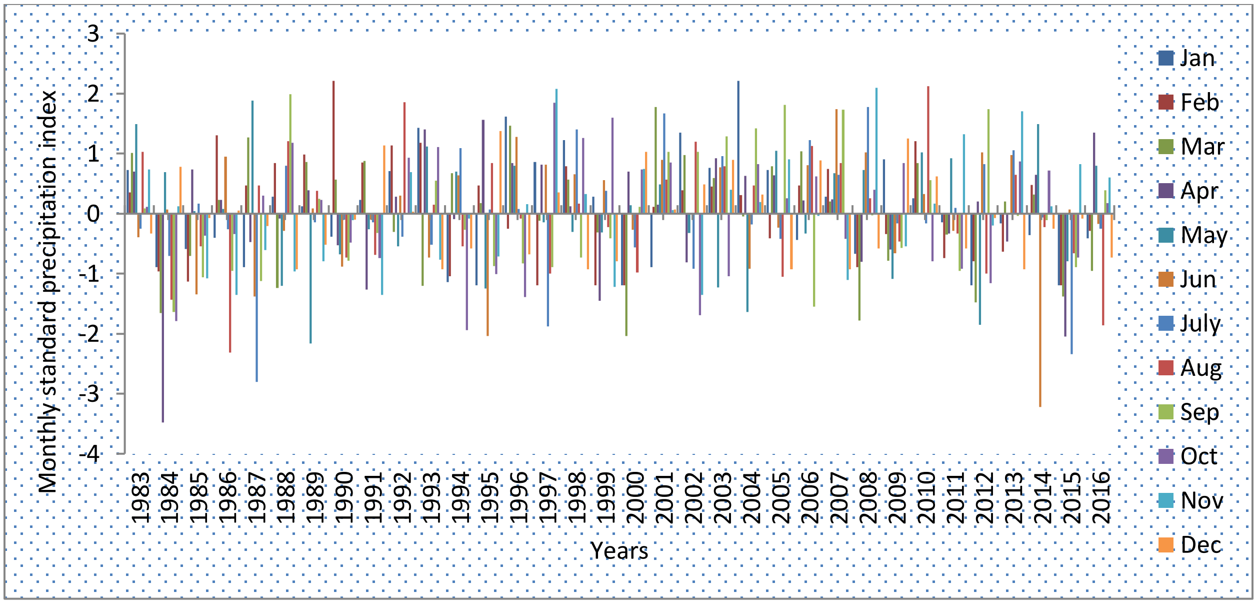


Figure 4.6: Standard precipitation index (SPI) result for monthly time scales in the study area

4.2.5. Temperature Trends

The study area experienced an average annual temperature of 18.80 °C during the 1983-2016 period.The report shows the average maximum temperature was 25.24 °C, while the average minimum temperature was 12.36 °C (Figure 4.7). The average maximum temperature for the 1983–1993 period is 24.97°C and the average minimum temperature 11.64°C; 25.17°C and 12.42°C for 1994–2005; 25.49°C and 12.83°C for 2006–2016.

The result shows statistically significant increasing trends ($p < 0.05$) for the 'mean maximum and minimum temperatures in the studied area. The average annual temperature increases by 0.04° C every year. Furthermore, the maximum temperature increased by 0.03°C, while the minimum temperature increased by 0.06°C (Figure 4.7)'.

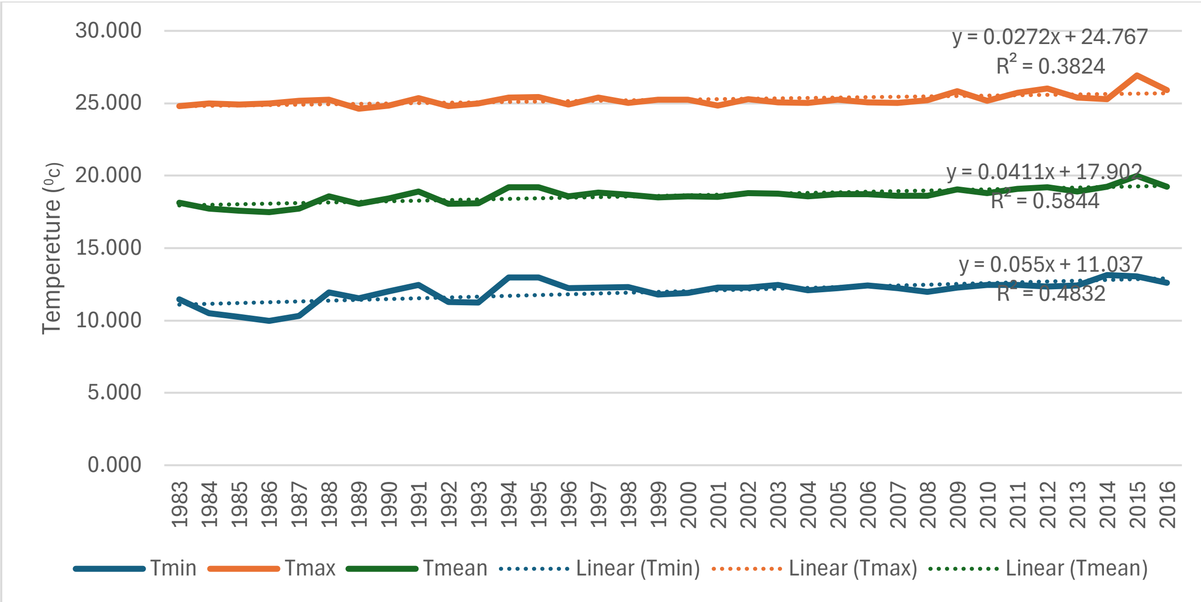


Figure 4.7: Temperature trends for maximum, minimum and mean temperature in the study area (1983-2016)

4.3. Discussion

The results of the first objective are discussed below. The study area showed considerable seasonal rainfall variability, rainfall distribution ranging from below-average to above-average between 1983 and 2016. The seasonal rainfall result shows a downward trend in *Belg* rainfall, whereas '*Kiremt* and *Bega* rainfall showed non-significant growing trends. Recent studies indicate that there have been no significant changes in the annual and Kiremt rainfall patterns in Ethiopia (Viste *et al.*, 2013; Wagesho *et al.*, 2013; Mengistu *et al.*, 2014; Matewos, 2019). For example, the *Kiremt* and *Bega* rains' seasonal rainfall distribution were both captured by the rainfall anomaly index. The irregular and unpredictable rainfall patterns during these wet seasons have a significant impact on the productivity of crops and livestock (Matewos, 2019). The coefficient of variation (CV) for the seasonal rainfall indicates significant variability in rainfall during the *Bega* and *Belg* seasons. An increase, while not a statistically significant trend, was indicated by annual rainfall observations. The results align with recent studies that have highlighted irregular seasonal and annual rainfall trends in Ethiopia (Alemu and Bawoke, 2019; Asfaw *et al.*, 2018; Esayas *et al.*, 2019). The results are in line with the findings of Benti and Abara's (2019) study on the distribution of annual rainfall in southern Ethiopia.

The study found that there was a slight increase in annual precipitation from 1995 to 2014, although the change was not statistically significant. According to Matthews et al. (2018), an increase of 1 degree Celsius in the annual temperature of the Niño 3.4SST region has the potential to result in a decrease of approximately 79mm per year, specifically in East Africa. It is important to consider adaptation measures for mitigating the adverse effects of climate change and related impacts during the dry season (Gashaw *et al*., 2014; Seleshi and Zanke, 2004). As per the study conducted by Cheung et al. (2008), there were no significant changes in the trends of annual rainfall in Ethiopia, both at the national and regional levels. The study conducted by Ayalew et al. (2012) investigated monthly and annual rainfall variability and trends in Ethiopia. The findings indicate that there were no significant long-term trends in the annual rainfall patterns. The result indicates a significant decrease in rainfall from 1995 to 2016, with an average annual rainfall deficit of approximately 60.86mm during this period. These findings align with previous research conducted by Jury (2010) and Bahaga *et al*. (2019).

The standard rainfall anomalies revealed positive and negative anomalies, which shows inter-annual rainfall variability. In 2015, there was a significant negative anomaly caused by the occurrence of El Niño in Ethiopia. This had a profound impact on rural communities, particularly in terms of their main livelihood activities (Gebregiorgis *et al*., 2019). According to several studies (Bayecha, 2013; Viste *et al*., 2013; Mersha and van Laerhoven, 2018; Matewos, 2019; Mekonen et al,2020), Ethiopia has experienced major historical droughts since 1984 that have adverse impact on the socioeconomic development. The occurrence of major droughts in Ethiopia over the past three decades has been found to be closely related with ENSO (El Niño-Southern Oscillation) events. According to Gleixner et al. (2017), in Ethiopia, there were several occurrences of El Niño events in 1987, 1991, 2009, and 2015. These incidents occurred during a prolonged drought period from April to November, which adversely affected the country's main cropping season. This drought period coincided with the country's primary cropping season. The recent 2015 El Niño related drought reduced annual household consumption by 8% and this exacerbating poor resilient food systems among rural communities in Ethiopia (Kasie *et al*., 2019). It is evident that most of the drought years recorded in the region were associated with the El Niño events whereas wet years coincided with La Niña years. Based on the SPI values, the area has encountered a range of rainfall conditions, varying from rainy to extremely dry years.

The study findings align with previous research that shows the frequency of drought cycles in Ethiopia has been changing over time (Amsalu and Adem, 2009; Shawul and Chakma, 2020). In 2015, Ethiopia experienced the impact of the East African drought, which was attributed to an El Niño event. This phenomenon significantly affected the *Belg* (March, April, and May) and *Kiremt* (June, July, August, and September) seasons, primarily in the northern and southern eastern regions of the country (Viste *et al*., 2013; Kasie *et al*., 2019). As a result, crops failed in the field, cattle died, and millions of people became starved (Gidey *et al*., 2018; Philip *et al*., 2018; Viste *et al*., 2013). The drought years had a notable effect on crop-livestock production during the *Belg* and *Kiremt* seasons, which are the primary cropping seasons in many regions of Ethiopia (Philip *et al*., 2018). The temperature analysis reveals a distinct upward trend in the study area's average minimum and maximum temperatures ($p<0.05$) level.

The recent studies conducted by Mekonen *et al*. (2020) and Abebe (2017) have reported an increase in the average yearly temperature in Ethiopia over the past 6 decades. According to Asfaw et al. (2018), there has been an increasing trend in both annual maximum and minimum temperatures in Ethiopia between 1901 and 2014. The impact of rising temperatures and declining precipitation in Ethiopia is particularly severe for crop farmers. Rain-fed agriculture is the primary source of income for over 80% of the country's population (Zewdu et al., 2020)'. There is a statistically significant increase in both the annual maximum and minimum temperatures ($p<0.05$). The findings are in line with those of Benti and Abara (2019), who has shown an annual increase in temperature trends. Overall, the results of this study show that there were substantial variations in temperature and precipitation during the specified observed period.

4.4. Summary

The purpose of this study was to investigate the patterns and fluctuations in rainfall and temperature during a 34-year period (1983-2016) in southern Ethiopia. The focus was on analyzing seasonal, annual, and monthly trends using time series station data. In this study, SAI, CV, PCI, and SPI were employed to assess rainfall variability and generate drought indices. 'Sen's slope estimator and the MK trend test are used to identify variations in rainfall patterns across the observed period. The findings show that the region experienced considerable rainfall variability and change that caused extended drought and flooding events over the observed period.

SAI and SPI results indicate an average inter-annual rainfall variability: the proportion of years with a below average rainfall distribution is 55.90%, with above average 44.10%. According to the Mann Kendall trend analysis, there is no significant trend of increased rainfall during the yearly, *Kiremt* (summer), and *Bega* (dry) seasons. However, the Belg (spring) season saw a notable decrease in rainfall, with implications for farmers and their agricultural activities, as this season is crucial for crop planting. The annual mean, maximum, and minimum temperature fluctuations in the specified study site have been recorded as 0.042^{0}C, 0.027^{0}C, and 0.056^{0}C' respectively. The results of the study may serve as an input for decision-makers to implement potential interventions that reduce the impact of rainfall and temperature variations. These interventions could increase the effectiveness of adaptation and mitigation measures at multiple levels.

CHAPTER FIVE: RESULTS AND DISCUSSION ON FARMERS' KNOWLEDGE OF CLIMATE CHANGE AND USE OF CLIMATE-SMART FARMING PRACTICES FOR ADAPTATION

5.1. Introduction

This chapter gives an overview of farmers' knowledge and perspectives of climate change, as well as response approaches in the research area. The chapter explores the impact of socioeconomic and demographic factors on farmers' knowledge of climate change and variability. The chapter focuses on the implementation of CSA measures by farmers as a means of adaptation measures on their farming plots. Furthermore, this chapter examines the implementation of CSA measures and their impact on agricultural productivity. It also identifies the crucial factors that affect the adoption of CSA measures.

5.2. Results

The results obtained for specific objective two are presented in the sections below.

5.2.1. Socio-demographic background

The descriptive statistics indicated that about 80.5% of the survey participants are male headed. The household size varies between five and seven family members on average. The average farming experience of local farmers in the area is about 25 years. Concerning the households' level of education, 37.5% of the heads of family attended primary school, and only 1% of the households attended tertiary school level. On average, 36.74% of farmers have straw/grass houses, 29.68% have corrugated iron houses, and the remaining have both straw and iron houses. About 45.4% of farmers are between the ages of 47 and 66, 33.12% are between the ages of 27 and 46, and 21.4% are between the ages of 67 and 86. Table 5.1 summarizes the findings from the study site's farmers' awareness and perception of climate change and associated risk.

Table 5.1. Farmers' awareness and perceptions of climate change and shocks

Farmers response to climate change and variability	Lemisuticho (%) (n = 238)	Begedamo (%) (n=147)	χ2 test
Perception of climate change			5.011
Yes	86.61	76.99	
No	13.39	23.01	
Temperature trend in the last 30 years			11.79
Increase	71.97	71.92	
Decrease	13.81	11.64	
No change	6.28	9.59	
Don't know	7.95	6.85	
Rainfall trend in the last 30 years			0.878
Increase	35.15	37.89	
Decrease	50.63	55.67	
No change	7.53	8.90	
Don't know	6.69	7.53	
Hot days in the last 30 years			6.617
Increased	73.22	71.23	
Decreased	13.81	8.22	
Stayed the same	6.28	12.33	
Don't know	6.69	8.22	
Rainfall days in the last 30 years			
Increased	35.63	42.47	2.80
Decreased	50.98	39.73	
Stayed the same	7.98	10.27	
Don't know	5.44	7.53	
Level of recent precipitation (5-10 years)			6.836
Very high	7.95	5.48	
High	37.24	32.19	
Normal	21.76	28.08	
Low	26.36	21.92	
Very low	6.69	12.33	
Encountered drought in the last 30 years			2.875
Yes	58.16	63.70	
No	34.73	32.88	
Don't know	7.11	3.42	
Flooding event in the last 30 years			5.253
Yes	59.00	68.49	
No	38.08	30.82	
Don't know	2.93	0.68	
Pest and disease occurrence in last 30 years			3.626
Yes	90.79	86.99	
No	5.86	10.96	
Don't know	3.35	2.05	

Farmers have reported an increase in temperature and a decrease in rainfall patterns during the last three decades. This tendency has become more apparent in the last five to ten years, with a rise in temperature and a decrease in rainfall distribution. An average of 81.8% of respondents from households in both study sites show that they have observed climate change, 71.95% responded that they have observed temperature increase, and 53.15% reported that rainfall variability and decreasing trends were observed. These results come from the interviews that were conducted at both study sites (Table 5.1). The survey participants provided information regarding the primary changes in rainfall and temperature that they have observed in their respective locations over the past decade. About 71% of the participants indicated that they have observed a growing level of unpredictability in the trends of rainfall and temperature. Farmers' agricultural activities have been severely impacted by the unpredictability and varied nature of rainfall and temperature.

The FGDs and KIIs confirm there has been erratic and intense rainfall distribution in the last decade and that this had a significant impact on farming activities. The participants in the FGD highlighted that widespread variations in temperature and the distribution of rainfall have become an urgent issue in the past five to ten years and have significantly impacted the ways in which the local communities make their living. The findings of the FGD indicate that many participants were informed of climate change; however, there were still few participants in the communities who did not grasp the phrase "climate change." This is because the questions are too broad, and the answers are too technical for farmers to easily understand. The findings of the survey suggested that most of the farmers who took part in the discussion had just a basic understanding about climate change. This revealed that 89% of farmers who participated in the FGD admitted that climate change is already happening, along with how it is affecting their farming operations.

One of the interviewees from Lemisuticho Kebele, who has resided in the study site for a period of 35 years, has stated the following: "*20 years ago, the amount of rainfall used to have a relatively normal pattern and it was sufficient for planting. However, in the recent decade, the duration and number of rainy seasons in both belg and meher/harvesting season had declined. For example, in 2020/2021, rainfall started in July and lasted in the mid of September, and the problem of rainfall become very difficult and unpredictable. In the past, rain typically began in belg season from May and continued through September a sometimes extends to first week of October, but this year's rainfall is happening less frequently compared to the previous time. Hence, this will highly affecting my agricultural activities*".

Key informants from Begedamo Kebele, who have resided there for 25 years, provided valuable insights on temperature change: "*temperature is increasing at an alarming rate when compared to the previous two decades. Several water springs in our locality have dried up as the temperature has risen, and the volume of water in nearby rivers has decreased when compared to the previous two decades. "Because water supplies for livestock and human consumption are getting scarce, we must travel long distances to obtain water for drinking*".

5.2.2. Farmers perceived impacts of climate change and variability

Table 5.2 presents the outcomes of farmers' perceived effect of climate change and variability on their means of livelihoods. According to smallholder farmers' report, climate change and the unpredictable pattern of rainfall pose significant threats to their means of subsistence. Farmers were asked to indicate how much climate change and variability influenced their means of subsistence. Farmers claimed that major sources of livelihood, such as economic, environmental, physical, human, and social systems, were severely impacted by climate change and fluctuation. According to farmers report during the interview period, climate change and its consequences have had a significant impact on their livelihood systems. These effects include a reduction in crop production (85.85%), a loss of household income (89.57%), a drop in the productivity of agricultural land (82.5%), food shortages and insecurity (79.47%), a rise in food prices (92.94%), and a rise in the cost of agricultural inputs (74.26%).

Table 5.2. Smallholder farmers' perceptions of the impact of climate change-related events in Lemisuticho and Begedamo Kebele

Perceived climate-related impact	Lemisuticho (n = 238) Respondents	Begedamo (n = 147) Respondents	Mean (%)
Crop yield decline	203(85.31)	127(86.39)	85.85
Loss of income	211(88.65)	133(90.47)	89.57
Decline in household consumption	204(85.71)	124(84.35)	85.03
Food shortage, food insecurity	184(77.31)	120(81.63)	79.47
Death of livestock and human mortality	90(37.82)	41(27.89)	32.855
Reduced productivity of agricultural land	166(69.75)	140(95.24)	82.5
Reduced water availability and quality	136(57.14)	80(54.42)	55.78
Increase cost of farm inputs	177(74.37)	109(74.15)	74.26
Increase cost of health care	102(42.86)	46(31.29)	37.075
Reduction in soil fertility	157 (65.97)	114(77.55)	71.76
Loss of Forest resources	167(70.16)	125(85.03)	77.595
Unemployment	106(44.53)	97(55.74)	50.14
Increase food prices	211(88.65)	143(97.23)	92.94

Farmers in FGD were asked about their primary sources of information about weather conditions, and they stated that they obtain climate information from a variety of sources (Figure 5.1). In both FGDs radio and development agents were frequently mentioned as the primary sources of information in both Lemisuticho and Begedamo kebele and radio is considered as the primary source of weather information.

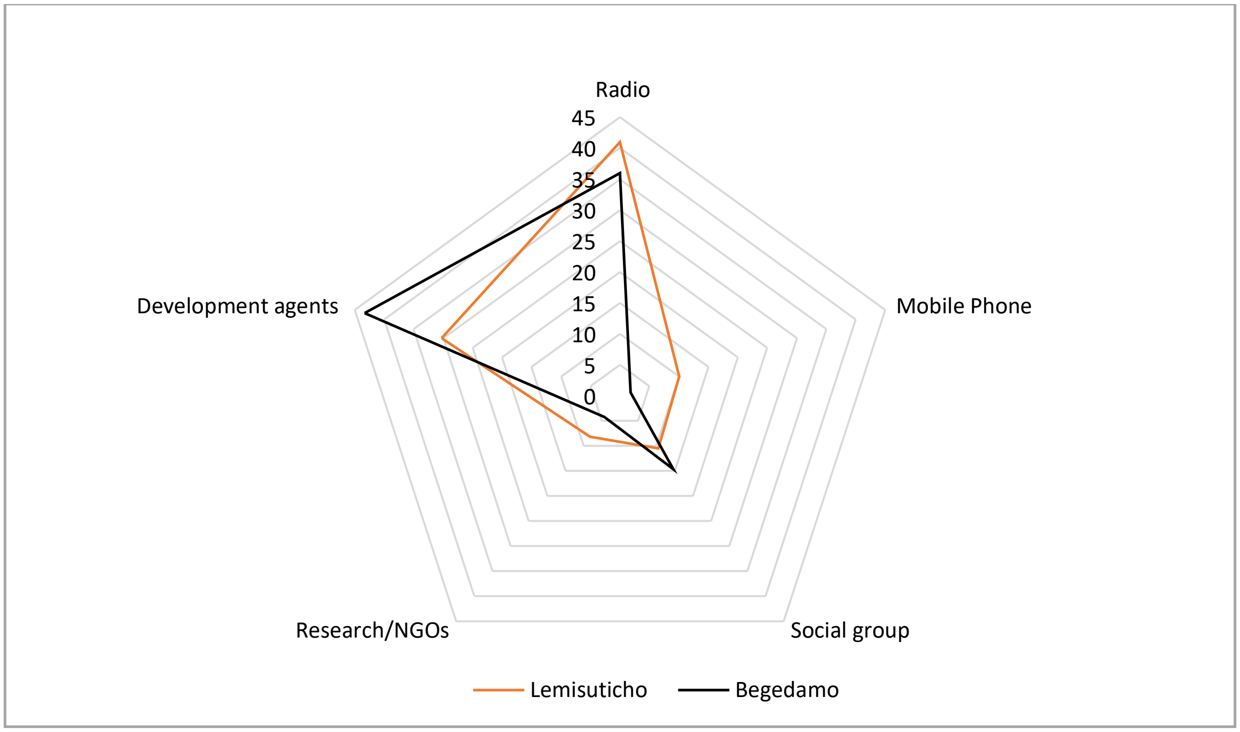


Figure 5.1. Channels of climate information for farmers in lemisutischo and begedamo

5.2.3. Farmers' adoption of CSA Practices

The benefits of different CSA measures that are now being utilized by the farmers are summarized in Table 5.3. The farmers in the research site apply different CSA measures such as improved crop varieties (high yielding beans, potato wheat), crop rotation (cereal/potato), SWC with biological measures, agroforestry systems (wood perennial crops), improved breeds (small ruminants), and residue incorporation (wheat/barely).

Table 5.3: Summary of the benefits of different CSA practices

CSA practices	Productivity	Adaptation	Mitigation
SWC with biological methods	Increase crop-livestock productivity	Reduce erosion, increase moisture, increase income diversification	Reduce emissions of GHG, enhanced efficiency of water use
Improved crop varieties	Increases yield	combats against pests, diseases, and drought	Reduce carbon emissions and chemical use
Crop rotation	Increase yield	Improve soil nutrient utilization	Carbon sequestration
Agroforestry	Increase crop-livestock productivity	Reduces soil erosion	Captures and stores more carbon
Improved breeds	Increase milk and meat production, increase income	Increase food and nutrition, increase income	Enhance input use efficiency
Controlled grazing	Increase livestock productivity	Improve soil organic matter, increase income, increase food and nutrition	Reduce methane emissions, carbon sequestration
Residue incorporation	Increase crop yield	Reduce soil evaporation and runoff	Increase water use efficiency, carbon sequestration
Green manure	Improve yield	Increases soil fertility	carbon sequestration
Cut and carry system	Increase livestock productivity	Reduce feeding costs and increase profitability	Carbon sequestration
Minimum tillage/mulching	Increase yield	Reduce soil evaporation and runoff	Carbon sequestration

According to the results obtained interview, it was found that approximately 83.58%of the participants reported implementing SWC practices with biological measures (Figure 5.2). This is because soil erosion is a common problem in the research region due to the steep slopes that make up the landscape, and it has a severe impact on soil fertility as well as agricultural production. The farmers in the study area employ a range SWC measures, such as terracing, soil bunds, and *desho* grass strips, to efficiently maintain resources and improve their agricultural practices. The research area exhibits a prone area to erosion, and implementing these practices can effectively enhance soil moisture levels while reducing runoff.

The most extensively used CSA practices among farmers are SWC, cut and carry system, crop residue and green manure incorporation. Natural grasses and agricultural wastes were what smallholder farmers relied on to feed their cattle. Growing fodder grass as the crop in their farm plot was an unusual practice, and it is only a very recent change to the original practices. Farmers have adopted new methods of livestock management based on a "cut and carry" feeding system to meet the requirements of feeding systems. The current situation involves a growing demand for communal pasture lands and a decline in fodder availability. The feed for cattle comes from different places at various times of the year and in accordance with the amount of produce that may be harvested by farmers.

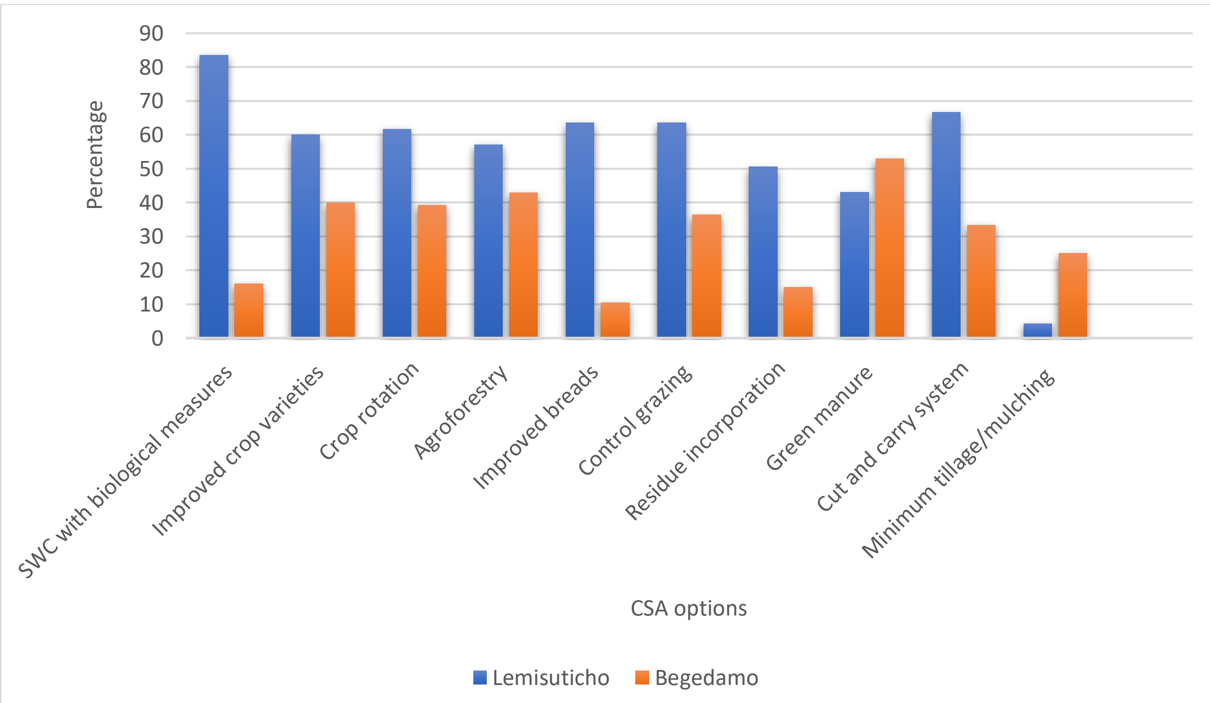


Figure 5.2 Farmers' adoptions of different climate-smart agriculture practices in the study sites

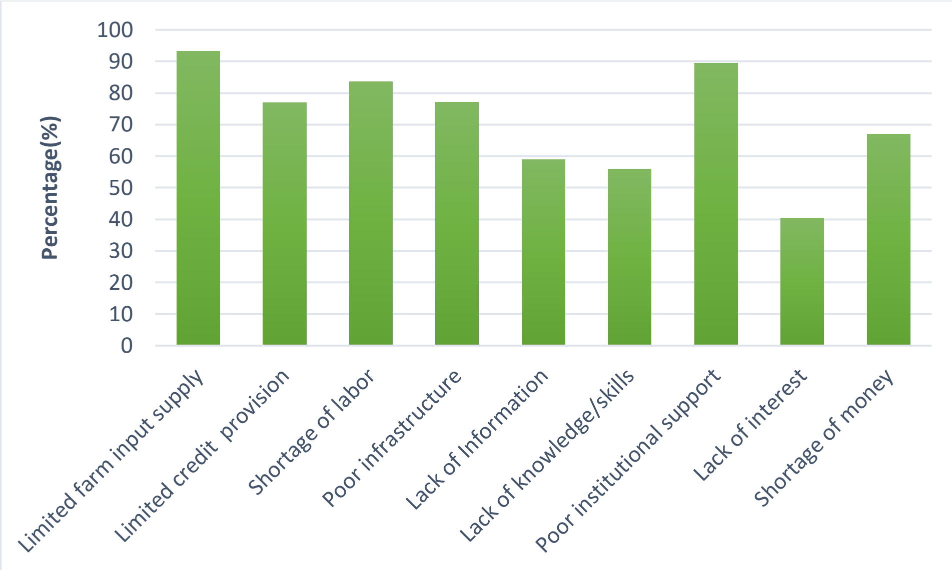
Farmers are adopting different CSA options to mitigate the impacts of climate change. The strategies encompass various approaches such as the utilization of improved crop varieties, implementation of the cut-and-carry system, implementation of SWC measures with a focus on biological measures, incorporation of agroforestry techniques, and the application of residue incorporation.

Table 5.4 estimates the overall impact of various CSA procedures on agricultural yield production among both adopters and non-adopters. It demonstrates the substantial gap in crop productivity between CSA adopters and non-adopters. Adopters have reported relatively higher yield production of vegetables, perennial crops, and cereals as compared to non-adopters. In comparison to non-adopters, CSA adopters have a greater average yield. For instance, adopters produce more wheat and potatoes than non-adopters during the production season, with yields of 36.84% and 40%, respectively (Table5. 4). Notably, the CSA adopters have a considerably larger yield than the non-adopters while using less fertilizer input and spending less on other expenses. According to farmers, the main challenges in their communities that hinder the implementation of CSA methods are inadequate agricultural inputs and weak institutional support. These issues are the key obstacles faced by farmers.

Table 5.4. Summary of aggregate crop yield production estimate

Crop type	**Adopters' ton /ha**	**Non-adopter's ton /ha**	**Mean difference ton /ha**	**%**
Wheat	3.8	2.40	1.4	36.84
Barley	2.75	2.00	0.75	27.27
Legumes	1.6	1.10	0.5	31.25
Potato	20.00	12.00	8.00	40.00
Enset	83.2	67.35	15.85	19.05
Vegetables	4.70	3.25	1.45	30.85

Farmers have identified inadequate finance services, a absence of meaningful information, and a lack of labor as the three primary obstacles that inhibit adaptation efforts (Figure 5.3). According to the findings, the three most important factors influencing farmers' perceptions on climate change are: annual income, market access, and the availability of climate information.



.

Figure 5.3 Constraints of climate change adaptation measures

5.2.4. Determinants of farmers' perceptions of climate change and adoption of CSA Practices

The Heckman probit selection model's findings for the outcome and selection models that affects farmers' CSA measures are shown in Table 5.5. 'Many of the explanatory variables in the outcome and selection models, along with their associated marginal effects, are statistically significant at the 0.05 level. The explanatory variables that were found to have a positive and significant impact on the likelihood of CSA practices included education, family size, gender, landholding size, farming experience, access to climate information, training received, social membership, ownership of livestock, farm income, and frequency of extension visits. For example, farmers with access to climate information were 20.2% more likely to adopt CSA practices than their counterparts who had no access to such information. In terms of education, 45.51% never attended school, 37.56% attended elementary school, 15.91% attended secondary school, and 1.02% attended college'. For example, the likelihood of farmers adopting CSA measures improves by 21.40% as the number of years spent in school increases. The marginal impacts quantify the probabilistic shift in how farmers will interpret and adjust to a one-unit shift in an explanatory variable. There is a relationship between the selection model and farmers' awareness of climate change and their commitment to take action to adapt to it.

Table 5.5. Results of the Heckman probit selection model

	Outcome model				Selection model			
Variables	**Regression**		**Marginal value**		**Regression**		**Marginal effect**	
	Coefficient	**z-Value**	**Coefficient**	**z-Value**	**Coefficient**	**z-Value**	**Coefficient**	**z-Value**
Age(Continues)	0.012	1.93	0.012	1.93	0.026	2.87	0.003	2.45
Education (Continues)	0.044	4.98	0.214	2.35	0.154	16.61	0.026	5.53
Familysize (Continues)	0.031	1.83	0.031	4.39				
Gender (Continues)	0.103	0.89	0.103	0.89	0.016	0.08	0.003	0.48
landholding size in ha (Continues)	0.160	8.46	0.161	2.17				
farming experience (Continues)	0.024	4.19	0.039	6.90	0.028	4.19	0.036	2.85
access extension (1/0)	0.137	3.43	0.137	4.58				
Distance to market (Continues)	-0.012	-1.71	-0.012	-1.71				
Access to climate info (1/0)	0.402	5.99	0.202	6.79	1.084	5.99	0.231	8.56
contact extension(frequency)	0.213	6.20	0.013	2.93				
Training received(1/0)	0.224	2.21	0.224	2.21				
access to credit(1/0)	0.001	0.01	0.001	0.01				
Social member (1/0)	0.206	20.29	0.106	2.59	0.620	1.70	0.005	2.72
Total Livestock Units (TLUs)(continues)	0.013	5.78	0.013	5.77				
Annual income (Continues)	0.235	2.68	0.235	2.68				
Soil fertility (1/0)	0.135	4.71	0.135	1.37				
Slop of farm plot(1/0)	-0.012	-0.14	-0.012	-0.14				
rainfall Var((Continues)					0.069	1.97	0.020	2.21
Constant	0.490	2.65			0.121	2.79		
Total observation 385								
Censored 79								
Uncensored 306								
Wald Chi- square (zero slopes) 82.45, p<0.001								
Wald chi-square (independent equation)	**10.25, p<0.001**							

The findings from the Heckman probit selection model shows that farmer’s education level is directly related to the amount of agricultural output they generate. Education may improve a farmer's capacity to obtain climate-related information, evaluate that knowledge, and easily comprehend it; as a result, the farmer is better able to devise potential solutions to problems caused by climate change and appropriate response mechanisms.

5.3. Discussion

The study investigated the farmers' understanding and awareness of climate change, as well as their adoption of CSA practices as adaptation strategies. The results indicate that most farmers (81.80%) have reported observing changes in the local climate. More specifically, 53.15% of respondents reported less rainfall and 71.9% of respondents reported higher temperatures. The results align with a study carried out in the ‘Central Rift Valley of Ethiopia’ by Hundera *et al.* (2019), where 90.3% of participants stated that the climate is changing.

The findings are supported by meteorological data, indicating a decrease in precipitation and a increase in temperature. Farmers have reported an escalation in the incidence of droughts, floods, pests, and diseases, which has been attributed to the impact of climate change. A farmer from Begedamo Kebele who took part in the FGD indicated that there was observed significant change in rainfall patterns over the past five to ten years. Specifically, the rainfall has become more irregular and short duration. Participants added that there was an increasing incidence of dry spells and prolonged droughts, which were affecting agricultural practices. Recent studies conducted by Concha (2018) in west Africa, Hundera *et al*. (2019), and Teshome *et al*. (2021) in Ethiopia found that a substantial number of farmers have knowledge about climate change and its adverse effect on agricultural production. The farmers who participated in the FGDs from Lemisuticho *kebele* emphasized that the rainy seasons as well as the times for planting, cultivation, and harvesting were predictable approximately three decades ago, and farmers used to cultivate their agricultural practices in good weather patterns. However, in recent decades, farmers have experienced unpredictable changes, such as a short duration of rainfall, massive flooding, crop failures in the field, crop-livestock pests and diseases, and human health problems. FGD participants from Begedamo kebele also reported that erratic rain and erosion are growing more and more common, which has led to soil fertility loss, land degradation, and poor agricultural yields.

The temperature rise may lead to a prolonged dry season. The changes have been notably significant in the past 5-10 years. This finding aligns with the outcomes of a study carried out in Ethiopia by Teklewold *et al.* (2019). The study found that smallholder farming systems are impacted by the unpredictability of rainfall and temperature.

Hundera *et al*. (2019) did a study to examine the perceptions of farmers in the Central Rift Valley of Ethiopia. The study indicates farmers hold the belief that the climate has experienced changes, and this has influenced their agricultural practices. Weldegebriel and Prowse (2017), who carried out their research in the northern region of Ethiopia, found that growing trends of temperature and rainfall variables influenced smallholder farmers' agricultural activities. Minda *et al.* (2018) did a study on the factors that affect adaptation measures in Ethiopia. The farmers emphasize that severe crop failure, extensive soil erosion, and a lack of water are all caused by climate change.

Participants in both focus group discussions added that droughts have affected many people in the research area over the previous three decades, with some of these droughts being unprecedented in the country's drought history. Farmers' drought reports are consistent with meteorological findings and are linked to 'El Niño Southern Oscillation (ENSO)' events such as those that occurred in 1984,1987, 1991, 1997, 2001, 2009, 2015, and 2019. For instance, the farmers reported on the 2015 drought lasted from April through November, which is the study area's main planting and agricultural season. The smallholders' perspectives of climate change and its impact are consistent with current studies (Dapilah and Nielsen, 2020; Apollo and Mbah, 2021).

Farmers' responses indicate that climate change has significantly impacted their means of livelihood. Most farmers, approximately 85.85%, have reported a decrease in agricultural production during the 2020/2021 production year. The results are aligned with the study made by Araro *et al.* (2019) who found that about 52.2% of smallholders in the southwest part of Ethiopia shown a decline in land productivity due to climate change and this decline led to decreased crop yields. Megersa *et al.* (2014) found that pests and diseases are caused by climate change, which lowers crop production and livestock productivity in southern Ethiopia. According to Mavhura *et al.* (2021) report on how climate change is affecting Zimbabwean farmers' livelihoods, agricultural crops have been negatively affected by climate change. Teshome *et al.* (2021) indicated that the small farming system in Ethiopia is adversely by climate change.

Furthermore, Kogo *et al.* (2021) and Mairura *et al.* (2021) indicated that climate change has negatively affected crop production and food security in Kenya. Climate change affects farmers' agriculture productivity as climate-related impacts worsen their livelihood systems (Dalton *et al.*, 2016; Islam *et al.*, 2021). Farmers' inability to achieve their goals has several negative effects, including how it is viewed psychologically, increasing rates of poverty, restricted access to food, and insufficient response to climate-related issues (Mekonnen *et al.*, 2021). Farmers need significant agricultural policy support to overcome climate-related shocks and achieve their goals (Genicot and Ray, 2017; Suckall *et al.*, 2017).

Having access to climate information significantly increases the likelihood of farmers adopting CSA practices by 20.2%. The findings align with the study conducted by Ado *et al*. (2019), which indicates that farmers' knowledge and perception of climate change are affected by the availability and accessibility of climatic information. For example, having more climate information, extension services, and input pricing could help decrease the barriers that exist in the way of putting CSA measures into action. According to Issahaku and Abdulai (2020) and Onyeneke *et al*. (2018), the adoption of CSA measures is primarily dependent on climate information. Adopters would have better experience of the CSA practice and become more aware of potential climate risks and uncertainty.

Climate information services can assist farmers in mitigating climate risk by enhancing information availability, knowledge exchange, and network connectivity, as well as implementing suitable adaption measures to reduce the negative impacts of climate change through adopting various CSA practices. Boz and Shahbaz (2021) suggested that the successful implementation of CSA practices in agriculture is contingent upon farmers' knowledge and perception of climate change and its consequences. Sardar *et al.* (2021) indicated farmers' aspirations to use CSA practices are contingent on their climate change knowledge and vulnerability). According to recent research, farmers' decisions to implement CSA techniques are influenced by their knowledge of climate change (Abegunde *et al*., 2020; Wassie and Pauline, 2020; Nyang'au *et al.*, 2021). Farmers in the research site indicated that social networks, radio, and development are the main sources of information on climate and farming activities related issues.

In addition, local communities have a common social asset called *"Iddir,"* which is a traditional system established for mutual aid and support in time of funeral services and collective managing of goods like farm management techniques. The area is also characterized by subsistent farming, poor access to essential resources, low-income, high poverty, and vulnerability to climate extremes (Dowsing *et al*., 2020).

Henriksson *et al.* (2021) found that farmers gain knowledge about climate change and its related effects by leveraging their social networks. This finding is consistent with the concept that social capital serves as the primary source of climate related information for farmers in their respective communities. Farmers that participate in social membership programs receive various benefits that enhance the likelihood of CSA adoption. This is primarily due to their access to valuable agricultural information from experienced senior members who possess better information on new agricultural practices. Zougmoré *et al*. (2021) shows farmers who are part of social institutions have a 10.6% greater chance of adopting CSAs than farmers who are not members of social organizations.

Participating in social groups is regarded as a valuable contribution to the development of the community's social capital, which plays an essential part in the exchange of agricultural experiences. In addition, having a robust social network makes it easier for people to join CSA measures (Abegunde *et al.*, 2020). The social group helps farmers as a means of communication and is critical in the process of implementing collective management of the farming system among rural communities (McNaught *et al*., 2014). This social institution provides the opportunity to share information with other farmers to have a relative awareness of climate change and innovative farming practices (Dapilah and Nielsen, 2020). Furthermore, membership in social organizations helps farmers to bridge information asymmetry and lower farmers cost of seeking for knowledge about new agricultural and climate related information (Sambrook *et al*., 2021). In the study site, radio is the primary source of weather information for farmers. This finding aligns with the research conducted by Henriksson *et al.* (2021), which highlights that radio is the primary medium for accessing weather information in Malawi. CSA approaches are helping farmers cope with drought, flooding, pests, and diseases (Amare and Simane, 2017; Sertse *et al.*, 2021). To effectively address climate change and variability, adaptation techniques are necessary (Keshavarz and Moqadas, 2021).

Farmers' responses about climate change influence their decisions to utilize CSA approaches as adaptation measures (Zerssa *et al.*, 2021). The implementation of CSA measures increases agricultural productivity, improvement in the climate-related resilience of farmers, and a reduction in GHGs emissions (Lipper *et al*., 2017). Establishing an anti-erosive structure that incorporates the association of grass and legumes to produce feed and the maintenance of soil moisture is required to control the serious soil erosion problems that have been plaguing the area. These biological conservation measures allow for the resolution of numerous issues at the same time, including soil fertility enhancement, the reduction of water retention, the problem of a lack of fodder, and the reduction of open grazing (Ayele *et al*., 2012).

In the context of Rwanda, Rutebuka *et al*. (2021) found that soil conservation practices that combined biological protection with terracing techniques were effective in preventing soil erosion. One of the most important things that can be done to protect agricultural productivity from ongoing climatic extremes and to strengthen farmers' ability to withstand them is to have them participate in SWC (Njeru *et al*., 2016). Farmers who participated in the FGD and KII reported that the daily duty of seeking for feed for their animals is a labor-intensive task that is typically carried out by the children or the women in the household. Depending on the season, as well as the number of animals in the herd, gathering forage might take anywhere from two to four hours of productive time per day. The finding consistent with Balehegn *et al.* (2020) on the possibility of improving livestock feed in developing countries, reported that livestock feeding is one of the primary challenges for many countries. This is because livestock production requires a considerable amount of feed, and fodder production has already been damaged by extreme drought, particularly in Ethiopia (Mengistu *et al*.,2017).

In order to increase agricultural productivity and adapt to climate change, farmers in the study area employ different CSA practices. The CSA measures include SWC, improved crops, agroforestry, livestock management, and crop residue incorporation. Farmers who are using these strategies reported that their soil fertility has improved since the intervention when compared to those who are using conventional techniques. Recent studies have revealed the significant benefits of CSA practices on soil fertility and crop yield (Anteneh and Asrat, 2020; Belay *et al*., 2021; Borrell *et al*., 2020; Waaswa *et al*., 2021).

For example, Waaswa *et al*. (2021) studied CSA farming practices and potato productivity in Kenya and reported that CSA-farmers generate 15 tons more potatoes per hectare than farmers who employ conventional agricultural techniques. According to Belay *et al*. (2021) report, adopting the CSA increases the yield of potatoes to more than 17 tons per hectare. Additionally, according to Anteneh and Asrat (2020), farmers may generate an average of 2.9 tons of wheat per hectare throughout the production season by using improved agricultural practices. As a result, the findings show that CSA adoption boosts agricultural yield and income while making efficient use of the resources at hand. The finding is in line with the findings of Marie *et al.* (2020), who studied the adoption of climate change adaptation strategies that enhanced crop productivity in Northwestern Ethiopia.

Analyzing the determinants that affect farmers' choices to adopt climate change measures is crucial for improving agricultural productivity and ensuring resilient livelihoods (Massresha *et al*.,2021). The model's results show that variables, such as household age and education level, agricultural experience, and climate-related knowledge, relate to a higher likelihood to recognize climate change and the related adaptation measures. Different studies shows that farmers' education status has a positive impact on their decision to adopt new farming practices since a farmer's access to education increases their ability to collect, understand information associated to the adoption of a CSA innovation (Deressa *et al.*, 2011; Challa and Tilahun, 2014; Asrat and Simane, 2017; Ramaano, 2021).

Education is essential for empowering farmers to address the challenges caused by climate change. Education plays a crucial role in strengthening the connection between smallholder farmers and agriculture extension providers, thereby enhancing the farmers' ability to adapt and survive. Farmers who possess a higher level of education tend to be more willing towards adopting modern farming techniques (Fentie *et al.,* 2019; Kumar *et al*.,2021). Educated farmers are more likely to use new farming techniques. A farmer with a strong educational background possesses a higher level of expertise and understanding when it comes to implementing improved adaptation measures (Walker *et al*., 2021). According to Aryal et al. (2020), there is an association between higher education and receiving institutional support for climate risk and adaptation measures in East Africa and Southern Asia including Ethiopia, Nepal, and Bangladesh.

By receiving and utilizing meaningful climatic information relevant to CSA operations, the literacy level helps to mainstream new agricultural practices and increase farmers' ability for adaptation (Abegunde *et al*., 2020). Deressa *et al*. (2011) and Arunrat *et al*. (2017) indicate that households with higher education level had a higher likelihood of adapting to climate change than those with lower levels of education due to new experiences in agricultural technologies. The effect of having a higher education level resulted in a greater exposure of farmers to new information and technology, which enhanced the likelihood of farmers adapting to their environments.

In a similar case, Croppenstedt *et al.* (2003) and Deressa *et al.* (2011) noted that higher-education households had a better probability of adjusting to climate change than lower-education households. Higher-educated farmers know better farming practices. They also have numerous income sources, which helps them invest in capital-intensive farming advances. Wainaina *et al.* (2016) indicates that there is an association between higher education levels among Kenyan smallholders and their increased usage of improved maize seeds and fertilizer. This can be attributed to their enhanced knowledge and the availability of additional sources of income. This result, however, contrasts with the one that was found by Wekesa *et al*. (2018), who found that the more years they spent in school had a positive influence on CSA practices.

‘Having a larger family can be beneficial in situations where there is a shortage of available labor, especially when adopting CSA practices. Most family members spent their time in the field due to the labor-intensive agricultural activities (Mvula and Dixon, 2021). The probability of farmers adopting CSA practices increases by 3.1% for each additional productive family member added to a household. This is because CSA activities are labor-intensive such as SWC with biological measures and agroforestry systems, and a considerable labor force is required for the efficient application of those agricultural practices on the farm plot (Ojoko *et al*., 2017). Farming experience affects farmers' climate change adaptation measures. Farmers with more farming expertise are more likely to respond to climate change (Deressa *et al*., 2009; Silvestri *et al.,* 2012; Li *et al*., 2017). The greater the farming experience, the high possibility of employing efficient adaptation strategies that improve farmers’ resilience to climate change (Mwungu *et al.,* 2018; Nyang'au *et al*., 2021). Most of the agricultural activities in the field require physical labor, and men are more likely than women to participate in such work (Tsige *et al*., 2020).

The age of the family head is an important element that can influence the adoption of improved agricultural techniques. Age has a lot to do with how much a farmer knows and how much farming experience they have. Elderly farmers exhibit greater capacity to evaluate the benefits and drawbacks of agricultural technology compared to their younger counterparts. Beshir (2014) found that there is a positive correlation between the age of the farm household head and the likelihood of adopting forage technology in Ethiopia. Feyisa (2020) found that the age of the household head positively influences farmers' adoption of improved agricultural techniques. This is because older families, with their accumulated life experiences, tend to possess more knowledge about the benefits of new agricultural technologies. The probability of farmers adopting CSA programs increases by 3.90 percent for every additional year of farming experience gained from time spent working on farms. This finding aligns with a previous study conducted by Onyeneke *et al.* (2018), which indicated farming experience as a determinant factor in adopting CSA practices in Nigeria. Ringler et al. (2010) and Silvestri et al. (2012) found that experienced farmers are more climate change conscious. Thus, they are more likely to adapt to climate change and embrace CSA practices.

Teshome *et al.* (2021) found 94% male-headed households in eastern Ethiopia. Kristjanson *et al.* (2017) found that women in Saharan Africa are less equipped, marginalized, and less likely to adapt to climate change than men. Bryan *et al*. (2018) highlighted the importance of considering gender-sensitive adaptation measures in different local contexts to ensure the effective implementation of adaptation strategies. Cultural and socioeconomic constraints that limit women's access to land, knowledge of agricultural practices, and participation in non-agricultural activities may reduce technology adoption among female-headed families. Another important factor influencing farmers' perception and adaptation measures is land holding size of households. Land is the most important resource for agricultural production; the greater the availability of land that can be farmed, the greater the number of people that participate in CSA practices. For example, the survey result indicates that the percentage of farmers who participate in CSA practices increases by 16.10% for every additional hectare (ha) of cultivated landholding size. This means, larger land resources may be employed for a variety of agricultural approaches, which would lessen the risks associated with uncertainties.

5.4. Summary

The aim of this study is to assess the farmers' knowledge of climate change and their use of climate-smart agriculture (CSA) practices as a response to climate change. The study utilized a ‘multistage sampling methodology to collect data from 385 households in Southern Ethiopia. The study employed a Heckman probit two-stage selection econometric model to examine the determinants of farmers’ understanding towards climate change and their implementation of CSA techniques. The findings reveal that a significant proportion of farmers (81.80%) have reported the occurrence of climate change in their local area. More precisely, 71.9% of them have reported a rise in temperature, whilst 53.15% have witnessed a decline in the frequency of rainfall.

Farmers implemented several practices of CSA, including SWC techniques using biological methods, adoption of enhanced crop varieties, implementation of agroforestry, utilization of improved livestock breeds, adoption of the cut and carry system, controlled grazing, and incorporation of crop residues. The empirical findings demonstrated that farmers' response to climate change through the adoption of CSA practices was influenced by various factors, including education level, family size, gender, landholding size, farming experience, access to climate information, received training, social membership, livestock ownership, farm income, and availability of extension services. Additionally, the finding indicated that farmers' perspectives on climate change and variability were especially impacted by factors such as age, educational background, farming expertise, and access to climate-related information. To enhance the knowledge and understanding of farmers, it is imperative to prioritize the improvement of meteorological information accuracy, the reinforcement of extension services’ and the implementation of a gender-responsive adaptation approach. Agricultural policies should support farmers in enhancing their dependence on climate resilience farming systems while simultaneously addressing barriers to the adoption of CSA practices.

CHAPTER SIX: RESULTS AND DISCUSSION ON THE IMPACT OF CLIMATE SMART AGRICULTURE (CSA) PRACTICES ON HOUSEHOLD INCOME AND FOOD SECURITY

6.1. Introduction

This chapter gives an overview of the findings and the following discussions derived from specific objective three. The chapter provides an overview of descriptive statistics related to household characteristics, farm management practices, and sources of income for food security. The chapter provides a detailed analysis and draws conclusions based on the empirical data. The chapter discusses the findings of the average treatment effects of CSA adoptions, leading up to the summary and conclusion.

6.2. Results

The result obtained for objective three are presented in the sections below.

6.2.1. Socioeconomic characteristics of CSA adopters and non-adopters

Table 6.1 summarizes the variables used in the empirical study; selection criteria is derived from the literature. The model output shows there is a substantial socioeconomic variation among CSA adopters and non-adopters. Farmers who adopt CSA practices differ from those who do not in several ways, including landholding size, education, soil fertility, frequency of extension, training received, social membership, livestock ownership, perception of climate, and willingness to take risks with new agricultural practices. The average labor forces for CSA adopters and non-adopters are 4.333 and 3.25, respectively. Climate smart agriculture adopters have the capacity to employ more labor compared to non-adopters. Higher mean values generally indicate that these variables influence CSA adoptions. Employers who have adopted CSAs have significantly higher labor demand than those who have not.

This analysis considers the household income and food security status, as defined by the FCS, as an outcome variable. Climate smart agriculture adopters have a higher gross household income and food consumption score than non-adopters which is significantly different at the 1% level. Farmers who have implemented CSA practices generally experience higher FCS scores compared to their counterparts. The average FCS value for adopters is 43.70, while non-adopters have an average FCS value of 36.40. Similarly, farmers that have implemented CSA practices have a greater mean annual gross income than their counterparts. The mean annual gross income for non-adopters is 9,933.91 ETB (1 USD = 37.35 ETB), whereas the mean annual gross income for adopters is 15,209.41 ETB. The t-test results indicate a substantial difference in annual total income among CSA adopters and their counterparts.

Table 6.1. Summary of the variables included in the model

Variables	**Non-adopters Mean (SD)**	**Adopters Mean (SD)**	**P-value**
HH crop income log (in ETB)	9933.91(828.13)	15209.41(986.83)	0.002***
HH_FCS (food consumption score)	36.40(0 .434)	43.70(0.416)	0.001***
Age (years)	52.06(1.18)	49.41(0 .83)	0.200
Education (years)	2.84(0.22)	4.55(0.36)	0.050**
Family size(continues)	7.77(0.19)	7.21(0.15)	0.130
Family labor(continues)	3.25(0.24)	4.33(0.16)	0.050**
Gender (1/0)	0.79(0.03)	0.81(0.02)	0.360
Landholding size(hectare)	0.54(0.03)	0.65(0.03)	0.025**
Farming experience (years)	26.72(1.24)	25.02(0.80)	0.320
Distance to market (km)	0.82(0.03)	0.89(0.02)	0.210
Access to climate info (1/0)	0.07(0.03)	0.86(0.03)	0.023**
Soil fertility (1/0)	0.63(0.03)	0.78(0.02)	0.012**
Slope of farmp plot (1/0)	0.56(.04)	0.57(0.032)	0.130
Contact extension(frequency)	2.02(0.06)	5.78(0.06)	0.053*
Training received (1/0)	0.58(0.04)	0.82(0.02)	0.005**
Access to credit (1/0)	0.27(0.03)	0.28(0.02)	0.232
Social group membership (1/0)	0.66(0.015)	0.94(0.014)	0.025**
TLU	2.46(0.13)	4.46(0.13)	0.023**
Climate change perception (1/0)	0.67(0.021)	0.87(.022)	0.001***
Agri technology risk (1/0)	0.42(0.04)	0.72(0.02)	0.000***
Rainfall Var (coefficient of variation)	1.73(0.07)	2.02(0.09)	0.001***

Note: The numbers in parenthesis are standard errors. *, **, and *** represent the level of significance at 10%, 5%, and 1%, respectively. At the time of the survey 2020/2021, 1 USD = 37.35 Ethiopian Birr (ETB).

After questions about CSA implementation, dividing the households into adopters and non-adopters, both groups were asked about what farm management strategies were chosen and the frequency of their application (Figure 6.1).

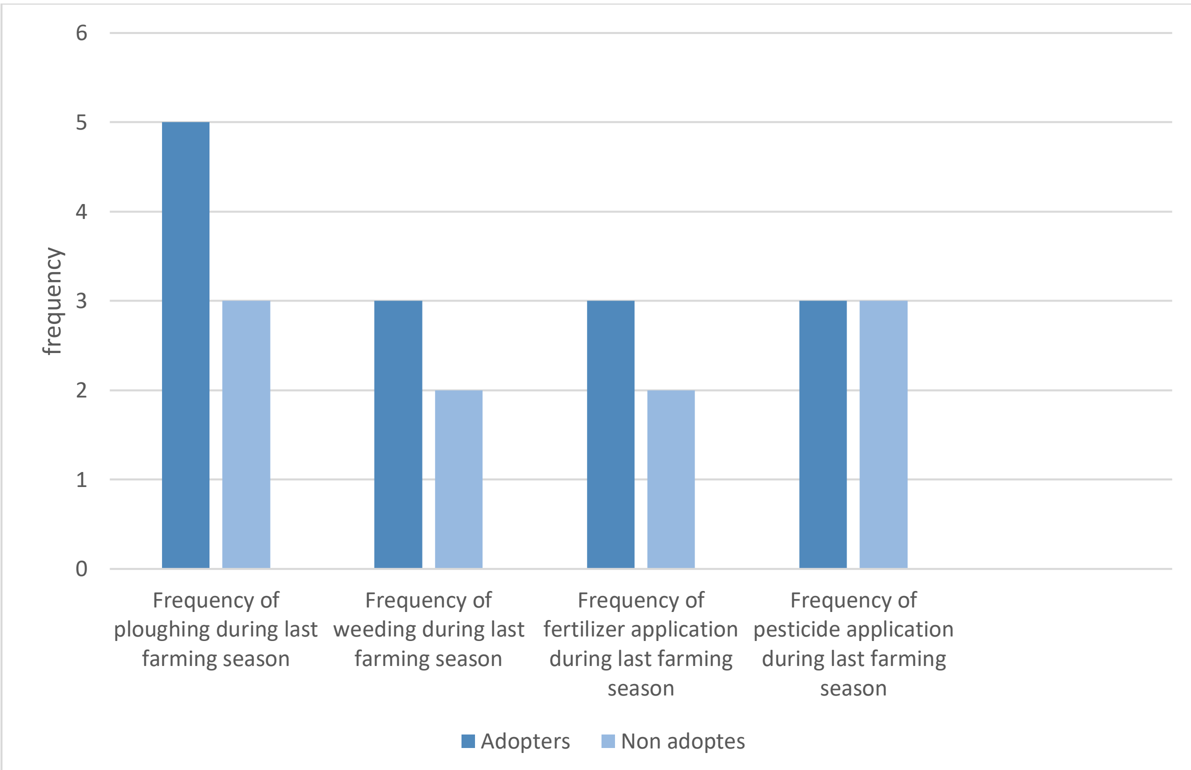


Figure 6.1: Selected farm management practices in farmers' farm plot

The study found that CSA activities require a higher frequency of farm management procedures as well as a higher level of commitment compared to conventional farming systems. CSA practices require more labor, and a rise in labor demand is critical for rising agricultural labor wages and, consequently, improving farming practices. For farmers in the study area, selling crops, cattle, trees, and other non-agricultural goods is their primary source of income (Figure 6.2). Of all farmers surveyed, 64.71% rely primarily on income generated from crop sales as their earnings of subsistence and primary source of income. Furthermore, farmers in the study area have been raising livestock, including improved animal varieties of animals (e.g., small ruminants).

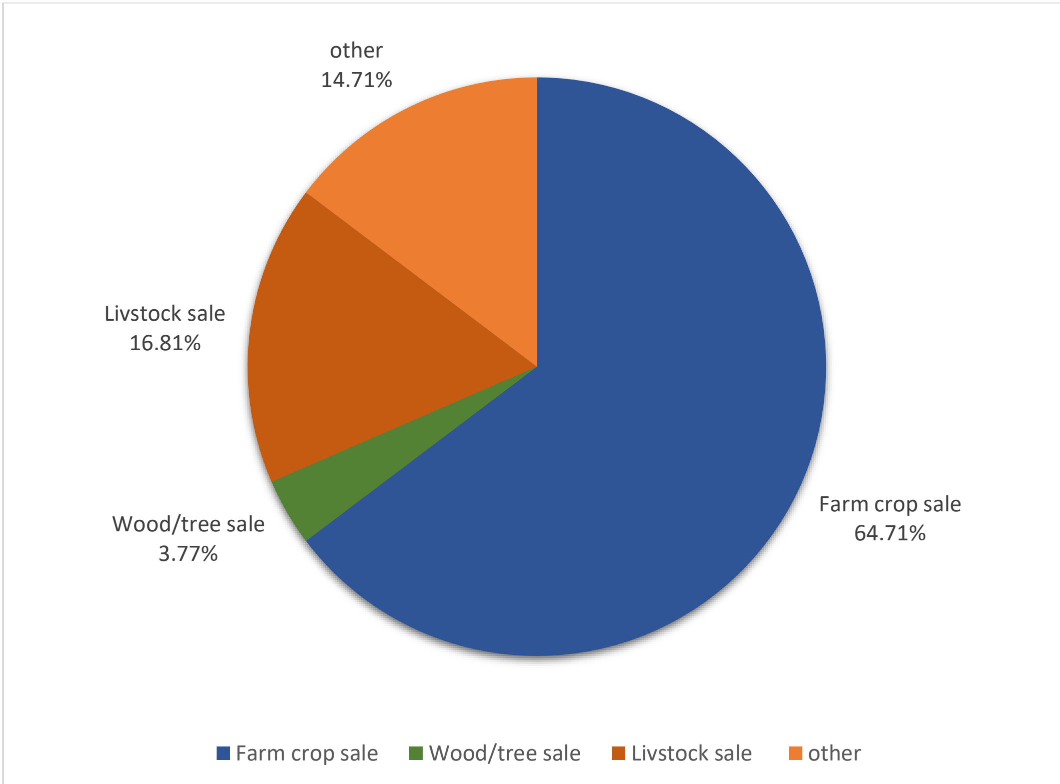


Figure 6.2: Farmers' sources of income in the study region

There are different kinds of agricultural crops cultivating in the study area including wheat, barley, legumes (e.g., beans), *Enset*/false banana, potatoes, fruits, and vegetables Farmers were asked, "What have been your monthly expenses for food, agriculture inputs, medication, and dressings (Appendix G). The expenditure approach for households is based on their total expenses, which approximate the total household, as measured by the expenditure on food items, non-food items, and other contributions for their total living expenses.

On the basis of crop production and FCS indicators, an assessment was done on the influence of CSA measures on the diversity of food consumed. Figure 6.3 illustrates the percentage of families into various categories of food consumption and shows that farmers in the region under investigation produce and eat a wide variety of foods. Farmers were surveyed about their food consumption over the past week from the date of surveyed , including a variety of cereals, tubers, pulses and nuts, vegetables meat and fish, dairy products, fruits, sugar and honey, and oil, fat, and butter.

The FCS of a household is a measurement of the household's dietary diversity. Sampled households, adopters, and non-adopters, were assigned to one of three food consumption categories based on their computed FCS: inadequate, borderline, or adequate. Out of the total number of households, 22.34% of adopters and 12.21% of non-adopters were found to fall into acceptable food consumption categories respectively. In addition, 31.17% of adopter households and 13.51% of non-adopters' households had borderline scores for food consumption. Meanwhile, 8.30% of households in the adopters' group and 12.47% of households in the non-adopters' group had poor consumption scores.

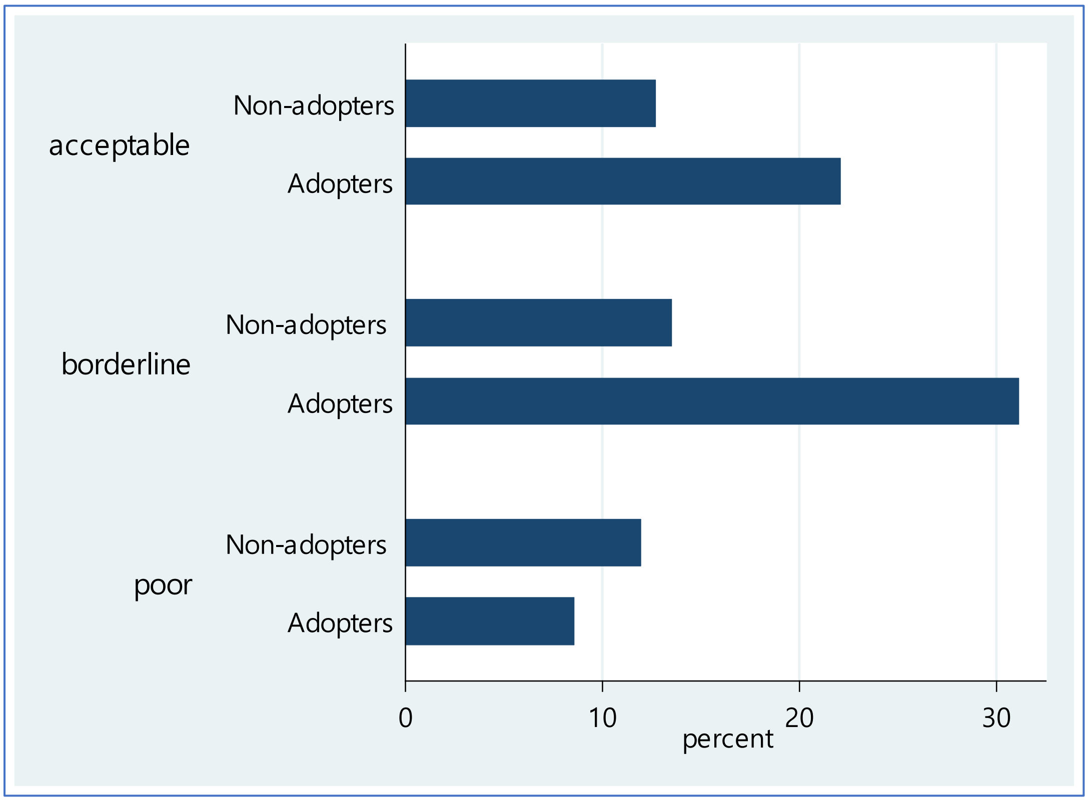


Figure: 6.3 Different categories of farmers' food consumption score

6.2.2. Estimation of propensity score and matching

A binary logit model is employed to make an accurate prediction on the chance of CSA implementation. The condition of overlapping and the tendency toward balancing have both been established and satisfied.

Adopters' estimated propensity scores range from 0.108 to 0.987, with a mean of 0.729 based on minimum and maximum criteria. Non-adopters, meanwhile, have a predicted propensity score of between 0.010 and 0.896, on average scoring 0.439. As a result, the range [0.108, 0.896] satisfied the common support criteria, while the remaining 68 observations lay outside this domain. Matching conditions were not employed for any households whose propensity score was outside the range of 0.108 to 0.896. In order to calculate the influence of CSA adoption on households' welfare, matching algorithms NNB, RM, and CM were utilized. Table 6.2 shows the propensity scores derived from the logit model. Table 6.2 presents the factors affecting the implementation of CSA measures, such as education, family size, family labor, landholding size, livestock ownership, and perceived soil fertility level.

Table 6. 2. The estimated results of the logit specification of the propensity scores

CSA Practices(dummy)	**Coef.**	**Std.Err.**	**z**
Age (continues)	−0.026	0.015	−1.700
Education (continues)	0.126	0.037	3.390***
Family size (continues)	−0.148	0.053	−2.800**
Family labor (continues)	0.142	0.052	2.730**
Gender (1/0)	0.515	0.323	1.590
Landholding size (continues)	0.920	0.325	2.830**
Farming experience (continues)	0.001	0.015	0.080
Distance market (continues)	−0.076	0.025	−3.020***
Climate information (1/0)	0.519	0.132	3.931***
Soil fertility (1/0)	0.906	0.296	3.060***
Slop of farmplot	−0.263	0.266	−0.990
Contact extension (continues)	0.029	0.011	2.636**
Training received (1/0)	1.587	0.290	5.480***
Access to credit (1/0)	−0.104	0.281	−0.370
Social member (1/0)	−0.606	0.663	−0.910
TLU (continues)	0.47	0.070	2.428**
CC perception (1/0)	−0.062	0.402	−0.150
Rainfall_var (continues)	−0.415	0.105	−3.960***
_cons	2.905	1.012	2.870**

Number of obs   385
Prob > chi2   0.000
Pseudo R2   0.2436

Note: *, **, and *** represent levels of significance at 10%, 5%, and 1% levels, respectively.

Figure 6.4 depicts the distribution and common support propensity scores before and after the matching process. For example, if the following conditions are met, the matching exercise is considered successful: there are no substantial differences in covariate distribution across matching groups; a low pseudo R^2, a lower standard means bias; and significant joint variables are rejected after matching. This shows from the covariate distribution after matching, the pseudo R^2 value (0.019), and the probability ratio's p-value (1.000) that the covariates are balanced among adopters and non-adopters in their respective farm households. The common support graph in Figure 6.4 shows significant overlap between CSA adopters and non-adopters.

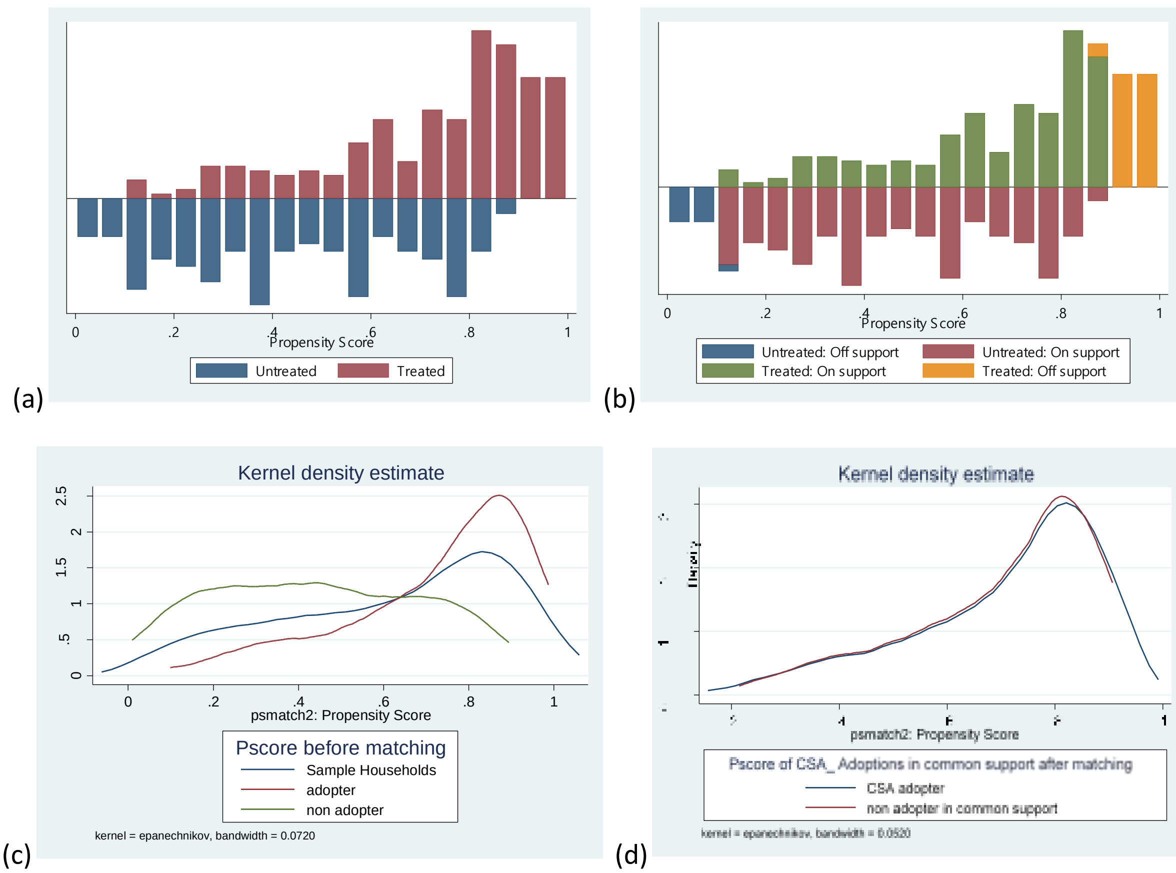


Figure 6.4: Propensity score distribution and common support region for propensity score estimation:(a) treated and untreated propensity score; (b) propensity score in common support region.

Treated on support indicated the individuals in groups who found a suitable match and treated off support indicated the individuals in the group who did not find a suitable match. Before matching, the propensity scores of adopters and non-adopters differ by about 70%. After matching, the bias was reduced to 4.7% from its previous value. It has been demonstrated that considerable differences emerged upon variables before matching; nevertheless, after such matching process, all the variables fall into insignificance and are balanced. Furthermore, the covariate balancing test results showed that the distribution of covariates among CSA adopters and non-adopters was comparable after matching. This was proved by the low pseudo R^2 value, insignificant P-value, and less than 20% mean standard bias.

6.2.3. Estimation of the average treatment effect of CSA adoptions

The study uses a variety of matching techniques, including radius matching, kernel matching, and nearest-neighbor matching, to examine the overall impact of CSA on FCS and crop income on a weekly basis. The evaluation of the Average Treatment Effect on Treated (ATT) in each of the three distinct matching algorithms reveals that engaging in CSA practices yields a positive impact on household crop revenue and FCS. Table 6.3 presents the estimated average treatment effects, derived from CSA adoption matching algorithms.

Table 6.3. The average impact of CSA adoption on household income and food security

Outcome variables	**Matching algorithms**	**Treated**	**Control**	**ATT**	**Pseudo-R^2**	**Standard Mean Bias**	**S.E.**	**Z -value**
Income	NNM	15048.0	9972.94	5057.07	0.027	5.0	1405.34	3.61
	CM	14875.3	9758.44	5116.91	0.031	4.8	1410.48	3.63
	RM	14875.3	9972.94	4902.41	0.134	7.1	984.69	4.98
FCS	NNM	43.43	37.15	6.27	0.036	8.0	1.96	3.19
	CM	43.96	35.81	8.15	0.037	4.3	1.06	7.63
	RM	43.72	36.24	7.47	0.134	7.5	0.56	13.18

The results of the ATT estimation for FCS are as follows: 6.27 using nearest neighbor matching, 8.15 for kernel matching, and 7.47 for radius matching. The average treatment impact on weekly FCS is 6.27–8.15% higher for CSA adopters compared to non-adopters. Adopters tend to have a more income of 4902.41- 5116.91 ETB compared to non-adopters. As shown in Table 6. 3., the adoption of CSA procedures has a large influence on household crop income per hectare. The analysis examined the overall effects of CSA and found that it had positive and statistically significant effects on household crop income and food consumption levels.

6.3. Discussion

The purpose of this research is to investigate the impact of climate smart agriculture activities on household income and food security in the study area. The study findings suggest that households that have implemented CSA practices are more likely to experience improved food security compared to households that have not adopted these activities. The average FCS among CSA adopters and non-adapters was found to be statistically significant at a high level of probability (P<000). The results are consistent with the research conducted by Aweke *et al.* (2020) and Teka and Lee (2020), which documented the beneficial impacts of enhancing agricultural techniques on the general well-being of households in Ethiopia. Adoption of CSA techniques in Ethiopia has a considerable positive impact on household welfare (Teka and Lee, 2020).

The average treatment effects of CSA adoption on crop revenue range from 4,902.41 ETB to 5,116.91 ETB higher than non-adopters. This finding aligns with the research conducted by Fentie and Beyene (2019), who examined CSA practices and the welfare of farmers in Ethiopia. They found that implementing CSA has a beneficial impact on household crop income and yield. Fentie and Beyene added that farmers can derive significant benefit from embracing CSA techniques and technology, since this approach offers the potential to enhance crop revenue and reduce levels of food insecurity. Farmers who adopt CSA practices have access to a better variety of foods and generate more income compared to non-adopters (Bedeke *et al.*, 2019). Furthermore, CSA practices improve farmers' ability to respond to the effects of climate change (Tesfay, 2020). The implementation of CSA practices on the farm plot depends on the availability of resources, institutional factors, and the severity of climate change conditions. As Keshavarz *et al.* (2021) indicated, the application of CSA practices is dependent on the specific local context.

Climate smart agriculture practices frequently used by the local famers in the study site includes crop rotation (cereal/potato), improved crop varieties (high yielding beans, potato wheat), agroforestry systems (wood perennials crops), improved breeds (small ruminants), and residue incorporation (wheat/barely). According to Lipper *et al.* (2017), CSA options have a positive effect on agricultural productivity. This, in turn, leads to increased household income, greater resilience among farmers, and a reduction in the negative effects of climate change.

Tadesse *et al*. (2021) employed various soil fertility indicators to assess the effects of CSA adoptions on the soil fertility status, crop output, and soil carbon levels of both CSA adopters and non-adopters within the same study area. These indicators include total nitrogen (TN), soil organic carbon (SOC), and plant-available phosphorus. According to the findings of Tadesse *et al*, the soil fertility of adopters' farm plots is significantly better ($p < 0.05$) compared with non-adopters. Furthermore, Tadesse *et al.* (2021) found that there are significantly higher levels of soil SOC, TN, and phosphorus in CSA adopters compared to areas that are not adopters. The study results show that the level of SOC in CSA measures was found to be 2.8–3.1 times higher in comparison to those who did not adopt CSA practices. Similarly, the levels of total nitrogen TN are 2.2–2.6 times higher in CSA, and phosphorus levels are 1.7–2.7 times higher in CSA adopters compared to non-adopters.

Crop productivity increased because of a combination of improved seeds and the implementation of more CSA practices. For instance, wheat crop output is increased by 30%–45% with CSA intervention compared to traditional farming, and this increase was significant at ($p < 0.05$), given the soil fertility indicators. According to Tadesse *et al.* (2021), the implementation of CSA intervention has been looked at in various landscapes, including forests, crops, and agroforestry, within the study area. The stock of SOC was assessed at a depth of one meter for both adopters and non-adopters. The findings show that the stock of SOC has shown an increase of 3.2%, 4.6%, 5%, and 6.9% for forestland, grassland, cropland, and agroforestry, respectively, when compared to non-adopters. The amount of SOC found in agroforestry landscapes was the largest (312 Mg C ha-1), followed by agricultural landscapes (229 Mg c ha-1). According to Mwongera *et al.* (2017) and Anang *et al.* (2021), adoption of CSA measures, including SWC, agroforestry systems, and residue incorporation, can lead to improved soil water retention, enhanced soil fertility, and increased potential for carbon sequestration.

This study indicates that CSA activities require a higher frequency of farm management practices as well as a larger level of commitment than conventional farming systems. This result supports previous research conducted by Akrofi-Atitianti *et al.* (2018) and Kangogo *et al.* (2021), which indicates that successful implementation of CSA on farms needs productive labor and effective resource mobilization. Asfaw *et al.* (2012) reported that CSA practices are labor-intensive and require skilled workers. According to recent studies, effective CSA adoption on the farm level demands productive labor, access to more financial resources (Kangogo *et al.,* 2021). Agriculture is the main sector in rural areas; increasing agricultural productivity through CSA practices improves both the financial stability of households and their access to nutritious food (Lipper *et al.,* 2014). The farmers in the study area employed various CSA practices to diversify their income streams. The adoption of CSA practices has a substantial and positive effect on the economic well-being of households, both through direct and indirect means. Direct implications include increased agricultural and livestock productivity as well as a decrease in production costs, which leads to in a rise in revenue and ensures that there is always food available (Aweke *et al.,* 2020). Furthermore, the practices of CSA measures have the potential to enhance the food supply by increasing the quantity of food available in the market.

According to farmers' responses during the interview, the selling of cattle is the second-largest source of income, following crop sales. According to Brüssow *et al.* (2017) and Aweke *et al.* (2020), who studied how the CSA practice affect food security among Tanzanian farmers, show that livestock production is considered as one of the primary sources of income for farmers. Climate smart agriculture adopters are believed to have a higher level of awareness regarding climate change and a greater tendency to engage with new farming techniques on their agricultural lands in comparison to non-adopters (Kalimba and Culas, 2020; Sardar *et al.,* 2021). The finding aligns with previous studies conducted on the adaptation farmers to climate change in Ethiopia (Gebrehiwot *et al.,* 2013), the adoption of CSA practices by smallholder farmers in Ethiopia who rely on maize production (Bedeke *et al.,* 2019), the association between climate change and farmer adaptation in Sub-Saharan Africa (Kalimba *et al.,* 2020), and the various factors that influence the adoption of multiple CSA technologies in Zimbabwe (Mujeyi *et al.,* 2020).

Hence, it is crucial for farmers to have regular interactions with agricultural extension workers and access to climate information in order to enhance their ability to adapt to climate change. The study findings show that the average treatment impact on weekly FCS varied significantly between CSA adopters and non-adopters. The impact for CSA adopters is 6.27-8.15 higher compared to non-adopters. This result is in line with Tafesse *et al*. (2020), who found that the impacts of moringa crop adopters on FCS are 6.2 times higher than those of non-adopters. However, the adoption adaptation strategies at the farm level faces challenges that have been recognized by local experts in the research area. For instance, lack of qualified workers at all levels is identified as the major barrier impeding the ability to implement climate change adaptation and mitigation measures. Saj *et al.* (2017) identify challenges that CSA practices faces, which are attributed to misconceptions in the scientific community and the response from the wider community. According to Taylor (2018), a major criticism of CSA practices is its narrow focus on technical solutions, without considering other important factors such as improvements in labor practices, consumption patterns, and land ownership issues.

The local experts during their interview also added that there is a lack of integration among organizations in the implementation and promotion of CSA practices. Contributing factors to this issue are insufficient coordination mechanisms at both local and regional levels and lack of operations to bring together and coordinate all the stakeholders involved in promoting CSA practices in its different forms (Autio *et al.*, 2021). Andrieu *et al*. (2019) argue that the process of co-designing climate-smart farming systems is complex and involves the interaction of knowledge, technologies, and institutional environments. To develop potential solutions, it is important to utilize a participatory and systems-based approach that incorporates the creation of scientific knowledge at the local level.

6.4. Summary

This study looks at how CSA practices affect food security and household income in Southern Ethiopia. To choose 385 households for the sample, a multistage sampling process was used. The study explored how the CSA intervention affected farm revenue and food self-sufficiency using survey data. Propensity score matching was used with a variety of matching methods, such as NNM, CM, and RM, to quantify the conditional impacts of CSA on household welfare.

In the study area, several CSA measures have been implemented to offset the negative effects of climate change and improve productivity in agriculture, income, and food security. Farmers that have adopted CSA practices have a FCS between 6.27 and 8.15 scores which was statistically significant at the 1% level. In addition, from the total sampled households, 34.55%, 44.68%, and 20.77% of households were categorized as acceptable, borderline, and poor statuses, respectively. Furthermore, households that adopted CSA practices have a 20.30% higher per hectare average annual farm income than non-adopters. The study suggests that effective extension services, accurate climate information, and policy support are required to promote and scale up CSA measures in the study area to improve farmers' adaptive capacity, farm income, and food security.

CHAPTER SEVEN: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

This chapter focuses on the thesis synthesis, general conclusion, and recommendation. The synthesis part summarizes the results discussions of the major findings across the objectives, followed by a general conclusion, recommendation, and policy implications.

7.1. Synthesis

The adverse impact of climate change presents a significant threat to the well-being of millions of people in developing nations, as well as to the stability of agriculture and food security (IPCC, 2022). Climate change has been identified as a major contributor to the development in crop pest incidents, decline in soil moisture levels, rapid depletion of soil nutrients, and significant decreases in crop production and yields (Khatri-Chhetri *et al.,*2017; IPCC, 2022; Jellason *et al.*, 2022). The observed decreases in rainfall, combined with the scarcity of improved high-yielding crop varieties, provide challenges for agricultural extension services. Additionally, the lack of accessibility to irrigation infrastructure could potentially jeopardize food security, limit export revenues, and greatly diminish net crop revenue (Jellason *et al.,*2022).

Ethiopia has been significantly affected by climate change, which has had a negative impact on its socioeconomic development (Bimir, 2022). The vulnerability of Ethiopia to climate change is mainly due to its heavy reliance on rain-fed agriculture for economic development, combined with its limited capacity to adapt to climate change (Addisu *et al*., 2019). Low adaptation capacity and a lack of awareness on climate change intensify the impact of climate change on farmers' livelihood systems (Feliciano *et al.,* 2022). The rural livelihood systems of Ethiopia are susceptible to climate change, although to various degrees, due to their dependence on rainfall (Feliciano *et al.,* 2022). Ethiopia has experienced multiple climatic and environmental shocks over the past three decades (Tofu *et al.,*2022). According to Tofu *et al.* (2022), the most significant climate change induced shocks in Ethiopia have been increases in rainfall and temperature change-related parameters, such as shifts in rainfall seasons, rain deficits, and erratic spatial distribution rainfall.

Furthermore, Tofu *et al*. (2022) highlights the challenges that Ethiopia experiences, including droughts, crop and livestock pests and diseases, and a scarcity of adequate pasture and freshwater. The analysis indicated that climate change induced shocks have had substantial negative effects on the livelihoods of smallholders, primarily through land degradation and decreased agricultural and livestock production. Despite national and local efforts in Ethiopia to mitigate climate change impacts, negative effects are occurring across the country. Many smallholder farmers are particularly affected; agricultural production systems are being severely impacted. These new risks brought on by climate change are probably to exacerbate the already difficult circumstances faced by many rural households in Ethiopia. It is vital to effectively coordinate collective efforts and take prompt actions on a worldwide and local scale to mitigate the fundamental factors contributing to climate change. Additionally, it is important to proactively prepare for and adapt to the inevitable consequences of climate change.

To effectively address the negative impacts of climate change, several CSA measures have been adopted within the research area. These measures attempt to improve agricultural output, income, and food security for farmers. According to Bazzana *et al.* (2022), CSA practices have proven to be a realistic strategy for enhancing the well-being and capacity of rural populations to adapt to climate change. This approach is particularly effective for farmers that have more opportunity to access financial resources, robust social networks, and an integrated food market. Despite this, there have only been a few studies conducted to better understand the adaptability of farmers in Ethiopia, particularly in the southern region, which is vulnerable to several climate related risks, such as recurrent droughts and floodings.

Studies have concentrated on exposures and traditional adaptation measures of climate change, instead exploring farmers' experiences of temporal variability and trends in temperature and rainfall patterns. It is critical to examine farmers' understanding and knowledge of climate change because this influences the implementation of CSA measures that enhance production and resilience. As a result, this research adds to the current body of knowledge by providing critical baseline information for future research and policy intervention in Ethiopia, which has recently launched a comprehensive climate change policy document called Climate Resilient Green Economy (CRGE) to reduce carbon emissions while supporting national adaptation plans.

The research findings can be used to complement the current CSA policy intervention and address institutional and external challenges that hinder smallholder farmers from adopting CSA practices. Smallholder farmers have traditionally been responsible for managing climate risk, apart from large climatic shocks. Climate change adaptation studies have frequently been conducted on a broad scale.

In order to develop impactful policies or initiatives aimed at mitigating the negative impacts of climate change, it is crucial to carefully consider adaptation measures that are tailored to the particulars of the local context. In addition, there has been a significant oversight in recognizing the farmers' understanding of climate change and their adoption of CSA measures as a means of adapting to it. Furthermore, the potential implications for household welfare have not received adequate attention. The study was carried out in Southern Ethiopia, an area known for its susceptibility to the effects of climate change (Mekonnen *et al.*, 2021; Shukla *et al.*, 2021). The purpose of this research is to investigate the adoption of CSA approaches within the context of small-scale farming in southern Ethiopia. To address the research problem, the study utilized a mixed methods approach. Hence, both quantitative and qualitative information data were collected simultaneously and combined to offer a comprehensive analysis of the research problem.

The meteorological findings indicate that the study area had significant variations of rainfall and temperature, leading to prolonged flooding and drought. The 'Mann-Kendall trend test revealed a slight increase in precipitation levels in the annual, Kiremt (summer), and Bega (dry) seasons. However, the *Belg* (spring) season experienced a significant decrease in rainfall at a significant level of ($P<0.05$). The yearly mean, maximum, and minimum temperature changes in the research area were 0.042^0C, 0.027^0C, and 0.056^0C, respectively. The study findings indicate that a significant majority of farmers (81.80%) reported that the local climate is changing. Specifically, 71.9% of farmers reported an increase in temperature, while 53.15% reported a decrease in the distribution of rainfall. Farmers employed various CSA methods, such as SWC techniques that involved the use of biological measures, improved crop varieties, agroforestry practices, better livestock breeds' cut and carry feeding methods, controlled grazing, and incorporation of crop residues.

The empirical evidence showed that factors such as 'education, family size, gender, landholding size, farming experience, access to climate information, training, social membership, ownership of livestock, farm income, and access to extension services significantly influence the ability of smallholder farmers to respond to climate change by adopting climate-smart agriculture measures. The study result added that farmer's age, education, farming experience, and availability to climate information all have a substantial impact on farmers perceptions of climate change and variability.

Compared with non-adopters, farmers who have adopted CSA practices have a FCS of 6.27–8.15. In addition, from the total sampled households, 34.55%, 44.68%, and 20.77% of households were found under categories of acceptable, borderline, and poor statuses, respectively. The result also confirms that households that implement CSA measures have an average annual income that was 20,30% higher compared to non-adopters. Farmers who used CSA were more likely to have higher incomes and more stable food supplies compared to those who did not use CSA measures. The study findings may provide decision-makers with a starting point to consider potential interventions in response to climate change. These interventions could enhance climate change responding measures at various levels. The study indicates that effective extension services, accurate climate information, and policy support are required to promote and expand CSA measures in the region to improve farmers' adaptive capacity, farm income, and food security. Agricultural policies should aim to strengthen farmers' activities in enhancing climate resilience and addressing challenges associated with the adoption of CSA) practices.

7.2. General Conclusion

Given Ethiopia's strong reliance on weather-sensitive livelihoods, its exposure to climate change and variability provides reason for great concern. Especially in the agricultural sector, a thorough understanding of temperature and rainfall variability is essential for creating successful adaptation and mitigation strategies. This study comprehensively analyzed temporal variability and the trend of rainfall distribution using meteorological data. Large variation was observed among seasons in the observing period. The SAI and SPI indices show drought years with the proportions of below and above average rainfall distribution anomalies. Reduction of precipitation in the research area affects agriculture production and availability of forage for the livestock feed, and food security.

The study revealed a distinct increase in both the maximum and minimum temperatures observed within the study area. The increasing temperature in the studied region has led to substantial water depletion because of evaporation. Agriculture, livestock farming, and drinking water supply are among the sectors that have been impacted. The result from the meteorological data shows that variations in temperature and precipitation have been observed throughout the specified period. Additionally, the study found that the SAI and SPI results agree with previous drought years associated with ENSO periods. Sociodemographic and institutional factors have a substantial impact on farmers' perceptions of climate change and variability.

The findings show, most farmers believe their local climate is changing, which is consistent with meteorological records of increasing temperatures and declining rainfall trends over decades. In response to the effects of climate change, smallholder farmers have implemented different CSA practices. The adaptation practices have been facilitated by local extension agents and non-governmental organizations. Additionally, farming experiences, education, gender, income, climate information, social group membership, risk-taking behavior, and extension services are key factors influencing CSA adoption. Maintaining feasible adaptation and mitigation investments using CSA practices and strengthening the ability of adaptation of households is imperative. The study implies the need to support smallholder farmers' CSA practice and technology with various policy support initiatives, including credit and farm inputs subsidies, to improve farmers' aspiration for future economic opportunities.

In Ethiopia, climate change and severe climate conditions have lowered agricultural yield and created food insecurity. The study examines how the application of CSA practices affects the income and food security of rural households in the study area. The study underlines the importance of CSA measures in terms of agricultural income and food security. Smallholder farmers are applying a range of CSA options to mitigate the negative effects of climate change and maintain the productivity of agriculture. The key findings show that smallholder farmers who have implemented CSA measures earn significantly more farm income and improved their food security compared with non-adopters. The role of CSA measures on farmers' welfare can be strengthened by providing subsidies, extension services, and accurate climate services.

7.3. Recommendation and policy implications

The study suggests that climate change adaptation measures should consider current climate change and variability. The study also promotes the timely and accurate climate information that the Ethiopian Meteorological institute should provide, such as seasonal forecasts and early warning systems. To do this, a thorough understanding of how climate change affects the livelihoods of smallholder farmers is vital. Climate change concerns require policy interventions that can transform climate-sensitive livelihood systems into climate-smart options.

The study also recommends that future studies increase their geographic scope to consider the entire SNNRP regions and geographical areas further, due to the region's diverse range of agroecology and landscapes.

The policy intervention to improve agricultural production and adopt appropriate CSA practices should consider reducing farmers’ exposure to climate risks and alleviating farmers’ difficulties while undertaking CSA practices and technologies. Adoption of CSA requires significant technical skill and knowledge. Thus, enhancing farmers’ education, providing accurate climate information, and strengthening extension services are some of the policy measures that need to be taken to promote CSA uptake. This study suggests that a portfolio of CSA practices for farmers living in diverse landscapes should be identified and prioritized for promotion and scaling up. Enhancing the experience and perception of climate change and its influences among smallholder farmers can facilitate the integration of more efficient CSA techniques into their farming practices.

Moreover, future studies need to be conducted comparing both program participants and non-participants before and after adoption of the CSA adoption to measure the dynamic of CSA interventions and capture possible unobserved heterogeneities.

This study only measured the aggregate effects of selected CSA practices. However, each CSA measure has a different level of impact on household income and food security, and an independent study is required to provide detailed CSA measures for designing specific interventions.

Reference

Abebe, G. (2017). Long-term climate data description in Ethiopia. *Data in brief*, *14*, 371-392.

Abebe, T. (2008). Climate change and development adaptation measures in Ethiopia. *Economic Focus (Addis Ababa, Ethiopia)*, *11*(1), 15-24.

Abegunde, V. O., Sibanda, M., & Obi, A. (2019). Determinants of the adoption of climate-smart agricultural practices by small-scale farming households in King Cetshwayo District Municipality, South Africa. *Sustainability*, *12*(1), 195.

Abera, A., & Wana, D. (2023). Effect of agricultural land management practices on the selected soil quality indictors: empirical evidences from the south Ethiopian highlands. *Environmental Systems Research*, *12*(1), 1-13.

Abidoye, B. O., & Odusola, A. F. (2015). Climate change and economic growth in Africa: an econometric analysis. *Journal of African Economies*, *24*(2), 277-301.

Addisu, A., Olago, D., Wandiga, S., Oriaso, S., & Amwata, D. A. (2019). Smallholder farmers vulnerability level to climate change impacts and implications to agricultural production in Tigray regional state, northern Ethiopia. *Journal of Agriculture and Crops*,12(5), 237-250. https://doi.org/10.32861/jac.512.237.250.

Ado, A. M., Leshan, J., Savadogo, P., Bo, L., & Shah, A. A. (2019). Farmers' awareness and perception of climate change impacts: case study of Aguie district in Niger. *Environment, Development and sustainability*, *21*, 2963-2977.

Adugna, T., Gazahgne, A., Mengistu, K., & Endrias, G. (2016). Food Security and vulnerability to climate change in Eastern Ethiopia. *Economics*, *5*(6), 81-88.

African Union Commission. (2015). Agenda 2063: The Critical Factors for Success. Agenda, 2063.Retrievedfromhttps://au.int/sites/default/files/documents/33126-doc-framework_document_book.pdf.

Aggarwal, P.K., Jarvis, A., Campbell, B.M., Zougmoré, R.B., Khatri-Chhetri, A., Vermeulen, S.J., Loboguerrero, A.M., Sebastian, L.S., Kinyangi, J., Bonilla-Findji, O. and Radeny, M. (2018). The climate-smart village approach. *Ecology and Society*, *23*(1).

Agnew, C. T., & Chappell, A. (1999). Drought in the Sahel. *GeoJournal*, *48*, 299-311.

Ajzen, I. (2011). The theory of planned behaviour: Reactions and reflections. *Psychology & health*, *26*(9), 1113-1127.

Akinnagbe, O. M., & Irohibe, I. J. (2014). Agricultural adaptation strategies to climate change impacts in Africa: A review. *Bangladesh Journal of Agricultural Research*, *39*(3), 407-418.

Akrofi-Atitianti, F., Ifejika Speranza, C., Bockel, L., & Asare, R. (2018). Assessing climate smart agriculture and its determinants of practice in Ghana: A case of the cocoa production system. *Land*, *7*(1), 30.

Alemu, M. M., & Bawoke, G. T. (2020). Analysis of spatial variability and temporal trends of rainfall in Amhara region, Ethiopia. *Journal of Water and Climate Change*, *11*(4), 1505-1520.

Alemu, T., & Mengistu, A. (2019). Impacts of climate change on food security in Ethiopia: adaptation and mitigation options: a review. *Climate Change-Resilient Agriculture and Agroforestry: Ecosystem Services and Sustainability*, 397-412.

Alewoye Getie, M., Legesse, S. A., Mekonnen, M., & Aschalew, A. (2020). Soil properties and crop productivity strategies as a potential climate variability adaptation option in Adefwuha Watershed, Ethiopia. *Earth Systems and Environment*, *4*, 359-368.

Altieri, M. A., Nicholls, C. I., Henao, A., & Lana, M. A. (2015). Agroecology and the design of climate change-resilient farming systems. *Agronomy for sustainable development*, *35*(3), 869-890.

Al-Zu'bi, M., Dejene, S.W., Hounkpè, J., Kupika, O.L., Lwasa, S., Mbenge, M., Mwongera, C., Ouedraogo, N.S. and Touré, N.D.E. (2022). African perspectives on climate change research. *Nature Climate Change*, *12*(12), 1078-1084.

Amare, A., & Simane, B. (2017). Assessment of household food security in the face of climate change and variability in the upper blue-nile of Ethiopia. *J Agric Sci*, *7*, 285-300.

Ampaire, E. L., Acosta, M., Huyer, S., Kigonya, R., Muchunguzi, P., Muna, R., & Jassogne, L. (2020). Gender in climate change, agriculture, and natural resource policies: insights from East Africa. *Climatic Change*, *158*(1), 43-60.

Amsalu, A., & Adem, A. (2009). Assessment of climate change-induced hazards impacts and responses in the southern lowlands of Ethiopia. FSS research report no 4. Forum for Social Studies, Addis Ababa.

Anang, B. T., Amesimeku, J., & Fearon, J. (2021). Drivers of adoption of crop protection and soil fertility management practices among smallholder soybean farmers in Tolon district of Ghana. *Heliyon*, *7*(5).

Anderson, S., & Elisabeth, F. (2015). USAID Office of Food for Peace food security country framework for Ethiopia FY 2016–FY 2020. *Washington, DC: Food Economy Group*, *13*.

Andrieu, N., Howland, F., Acosta-Alba, I., Le Coq, J.F., Osorio-Garcia, A.M., Martinez-Baron, D., Gamba-Trimiño, C., Loboguerrero, A.M. and Chia, E. (2019). Co-designing climate-smart farming systems with local stakeholders: a methodological framework for achieving large-scale change. *Frontiers in Sustainable Food Systems*, *3*, 37.

Anteneh, A., & Asrat, D. (2020). Wheat production and marketing in Ethiopia: Review study. *Cogent Food & Agriculture*, *6*(1), 1778893.

Antwi-Agyei, P., & Stringer, L. C. (2021). Improving the effectiveness of agricultural extension services in supporting farmers to adapt to climate change: Insights from northeastern Ghana. *Climate Risk Management*, *32*, 100304.

Apollo, A., & Mbah, M. F. (2021). Challenges and opportunities for climate change education (Cce) in East Africa: A critical review. *Climate*, *9*(6), 93.

Araro, K., Legesse, S. A., & Meshesha, D. T. (2020). Climate change and variability impacts on rural livelihoods and adaptation strategies in Southern Ethiopia. *Earth Systems and Environment*, *4*, 15-26.

Archer, E. R. M., Landman, W. A., Malherbe, J., Maluleke, P., & Weepener, H. (2021). Managing climate risk in livestock production in South Africa: How might improved tailored forecasting contribute? *Climate Risk Management*, *32*, 100312.

Argaw, S., Genetu, A., Vervoort, D., & Agwar, F. D. (2023). The state of cardiac surgery in Ethiopia. *JTCVS open*, *14*, 261-269.

Arndt, C., Robinson, S., & Willenbockel, D. (2011). Ethiopia's growth prospects in a changing climate: A stochastic general equilibrium approach. *Global Environmental Change*, *21*(2), 701-710.

Arunrat, N., Wang, C., Pumijumnong, N., Sereenonchai, S., & Cai, W. (2017). Farmers' intention and decision to adapt to climate change: A case study in the Yom and Nan basins, Phichit province of Thailand. *Journal of Cleaner Production*, *143*, 672-685.

Aryal, J. P., Sapkota, T. B., Khurana, R., Khatri-Chhetri, A., Rahut, D. B., & Jat, M. L. (2020). Climate change and agriculture in South Asia: Adaptation options in smallholder production systems. *Environment, Development and Sustainability*, *22*(6), 5045-5075.

Asare-Nuamah, P., & Botchway, E. (2019). Understanding climate variability and change: analysis of temperature and rainfall across agroecological zones in Ghana. *Heliyon*, *5*(10).

Asfaw, A., Bantider, A., Simane, B., & Hassen, A. (2021). Smallholder farmers' livelihood vulnerability to climate change-induced hazards: agroecology-based comparative analysis in Northcentral Ethiopia (Woleka Sub-basin). *Heliyon*, *7*(4).

Asfaw, A., Simane, B., Hassen, A., & Bantider, A. (2018). Variability and time series trend analysis of rainfall and temperature in northcentral Ethiopia: A case study in Woleka sub-basin. *Weather and climate extremes*, *19*, 29-41.

Asfaw, S., Shiferaw, B., Simtowe, F., & Lipper, L. (2012). Impact of modern agricultural technologies on smallholder welfare: Evidence from Tanzania and Ethiopia. *Food policy*, *37*(3), 283-295.

Asrat, P., & Simane, B. (2017). Adaptation benefits of climate-smart agricultural practices in the Blue Nile Basin: empirical evidence from North-West Ethiopia. *Climate change adaptation in Africa: fostering resilience and capacity to adapt*, 45-59.

Atwoli, L., Erhabor, G.E., Gbakima, A.A., Haileamlak, A., Ntumba, J.M.K., Kigera, J., Laybourn-Langton, L., Mash, R., Muhia, J., Mulaudzi, F.M. and Ofori-Adjei, D. (2022). COP27 Climate Change Conference: urgent action needed for Africa and the world. *The Lancet Oncology*, *23*(12), 1486-1488.

Auci, S., Castellucci, L., & Coromaldi, M. (2018). The impact of climate change on the distribution of rural income in Ethiopia. *International Journal of Environmental Studies*, *75*(6), 913-931.

Austin, K. G., Beach, R. H., Lapidus, D., Salem, M. E., Taylor, N. J., Knudsen, M., & Ujeneza, N. (2020). Impacts of climate change on the potential productivity of eleven staple crops in Rwanda. *Sustainability*, *12*(10), 4116.

Autio, A., Johansson, T., Motaroki, L., Minoia, P., & Pellikka, P. (2021). Constraints for adopting climate-smart agricultural practices among smallholder farmers in Southeast Kenya. *Agricultural Systems*, *194*, 103284.

Aweke, C. S., Lahiff, E., & Hassen, J. Y. (2020). The contribution of agriculture to household dietary diversity: evidence from smallholders in East Hararghe, Ethiopia. *Food Security*, *12*, 625-636.

Ayalew, D., Tesfaye, K., Mamo, G., Yitaferu, B., & Bayu, W. (2012). Variability of rainfall and its current trend in Amhara region, Ethiopia. *African Journal of Agricultural Research*, *7*(10), 1475-1486.

Ayele, S., Duncan, A., Larbi, A., & Khanh, T. T. (2012). Enhancing innovation in livestock value chains through networks: Lessons from fodder innovation case studies in developing countries. *Science and public policy*, *39*(3), 333-346.

Ayinu, Y. T., Ayal, D. Y., Zeleke, T. T., & Beketie, K. T. (2022). Impact of climate variability on household food security in Godere District, Gambella Region, Ethiopia. *Climate Services*, *27*, 100307.

Babatolu, J. S., & Akinnubi, R. T. (2013). Surface temperature anomalies in the river Niger basin development authority areas, Nigeria. *Atmospheric and Climate Sciences*, *2013*.

Bahaga, T. K., Fink, A. H., & Knippertz, P. (2019). Revisiting interannual to decadal teleconnections influencing seasonal rainfall in the Greater Horn of Africa during the 20th century. *International Journal of Climatology*, *39*(5), 2765-2785.

Balehegn, M., Duncan, A., Tolera, A., Ayantunde, A.A., Issa, S., Karimou, M., Zampaligré, N., André, K., Gnanda, I., Varijakshapanicker, P. and Kebreab, E. (2020). Improving adoption of technologies and interventions for increasing supply of quality livestock feed in low- and middle-income countries. *Global food security*, *26*, 100372.

Battistin, E. (2003). *Errors in survey reports of consumption expenditures* (No. 03/07). IFS Working Papers.

Bayecha, D. K. (2013). *Economic impacts of climate change on teff production in Lume and Gimbichu Districts of Central Ethiopia* (Doctoral dissertation, Sokoine University of Agriculture). https://www.suaire.sua.ac.tz/handle/123456789/477.

Bazzana, D., Foltz, J., & Zhang, Y. (2022). Impact of climate smart agriculture on food security: An agent-based analysis. *Food Policy*, *111*, 102304.

Becker, S. O., & Caliendo, M. (2007). Sensitivity analysis for average treatment effects. *The stata journal*, *7*(1), 71-83.

Bedane, H. R., Beketie, K. T., Fantahun, E. E., Feyisa, G. L., & Anose, F. A. (2022). The impact of rainfall variability and crop production on vertisols in the central highlands of Ethiopia. *Environmental Systems Research*, *11*(1), 1-19.

Bedeke, S. B. (2023). Climate change vulnerability and adaptation of crop producers in sub-Saharan Africa: A review on concepts, approaches and methods. *Environment, Development and Sustainability*, *25*(2), 1017-1051.

Bedeke, S., Vanhove, W., Gezahegn, M., Natarajan, K., & Van Damme, P. (2019). Adoption of climate change adaptation strategies by maize-dependent smallholders in Ethiopia. *NJAS-Wageningen Journal of Life Sciences*, *88*, 96-104.

Behailu, G., Ayal, D. Y., Zeleke, T. T., Ture, K., & Bantider, A. (2021). Comparative analysis of meteorological records of climate variability and farmers' perceptions in sekota woreda, Ethiopia. *Climate Services*, *23*, 100239.

Belay, A., Demissie, T., Recha, J.W., Oludhe, C., Osano, P.M., Olaka, L.A., Solomon, D. and Berhane, Z. (2021). Analysis of climate variability and trends in Southern Ethiopia. *Climate*, *9*(6), 96.

Belay, D. W., Asfaw, Z., Lulekal, E., & Kassa, B. (2021). Farmers' management of potato (Solanum tuberosum L.) late blight (Phytophtora infestans (Mont.) de Bary) and sprouting in Shashemene and West Shewa districts, Ethiopia. *Cogent Food & Agriculture*, *7*(1), 1925432.

Below, T. B., Schmid, J. C., & Sieber, S. (2015). Farmers' knowledge and perception of climatic risks and options for climate change adaptation: a case study from two Tanzanian villages. *Regional environmental change*, *15*, 1169-1180.

Benti, F., & Abara, M. (2019). Trend analyses of temperature and rainfall and their response to global CO2 emission in Masha, Southern Ethiopia. *Journal of Sustainable Agriculture, 34(1), 67-75.*

Bimir, M. N. (2022). Ethiopia's climate change policies in retrospect: from conservationism to green economy. *Energy Policy Advancement: Climate Change Mitigation and International Environmental Justice*, 163-183.

Birara, H., Pandey, R. P., & Mishra, S. K. (2018). Trend and variability analysis of rainfall and temperature in the Tana basin region, Ethiopia. *Journal of Water and Climate Change*, *9*(3), 555-569.

Birsan, M. V., Molnar, P., Burlando, P., & Pfaundler, M. (2005). Streamflow trends in Switzerland. *Journal of hydrology*, *314*(1-4), 312-329.

Bojnec, Š., & Knific, K. (2021). Farm household income diversification as a survival strategy. *Sustainability*, *13*(11), 6341.

Bonilla Findji, O., Ortega, A., Eitzinger, A., Recha, J.W., Ambaw, G., Abera, W., Tamene, L.D., Demeke, G., Desalegn, M., Mekonnen, K. and Radeny, M. (2020). How are smallholder households coping with and adapting to climate-related shocks in Doyogena climate-smart landscapes, Ethiopia? https://cgspace.cgiar.org/handle/10568/111480.

Borrell, J.S., Goodwin, M., Blomme, G., Jacobsen, K., Wendawek, A.M., Gashu, D., Lulekal, E., Asfaw, Z., Demissew, S. and Wilkin, P. (2020). Enset-based agricultural systems in Ethiopia: A systematic review of production trends, agronomy, processing and the wider food security applications of a neglected banana relative. *Plants, People, Planet*, *2*(3), 212-228.

Boz, I., & Shahbaz, P. (2021). Adoption of climate-smart agriculture practices and differentiated nutritional outcome among rural households: A case of Punjab province, Pakistan. *Food Security*,13(4), 913-931.

Bradley, G. L., Babutsidze, Z., Chai, A., & Reser, J. P. (2020). The role of climate change risk perception, response efficacy, and psychological adaptation in pro-environmental behavior: A two nation study. *Journal of Environmental Psychology*, *68*, 101410.

Brida, A. B., Owiyo, T., & Sokona, Y. (2013). Loss and damage from the double blow of flood and drought in Mozambique. *International Journal of Global Warming*, *5*(4), 514-531.

Brüssow, K., Faße, A., & Grote, U. (2017). Implications of climate-smart strategy adoption by farm households for food security in Tanzania. *Food security*, *9*, 1203-1218.

Bryan, E., Bernier, Q., Espinal, M., & Ringler, C. (2018). Making climate change adaptation programmes in sub-Saharan Africa more gender responsive: insights from implementing organizations on the barriers and opportunities. *Climate and Development*, *10*(5), 417-431.

Caliendo, M., & Kopeinig, S. (2008). Some practical guidance for the implementation of propensity score matching. *Journal of economic surveys*, *22*(1), 31-72.

Callo-Concha, D. (2018). Farmer perceptions and climate change adaptation in the West Africa Sudan Savannah: reality check in Dassari, Benin, and Dano, Burkina Faso. *Climate*, *6*(2), 44.

Carleton, T. A., & Hsiang, S. M. (2016). Social and economic impacts of climate. *Science*, *353*(6304), aad9837.

Carletto, C., Zezza, A., & Banerjee, R. (2013). Towards better measurement of household food security: Harmonizing indicators and the role of household surveys. *Global food security*, *2*(1), 30-40.

Carlos, S., da Cunha, D. A., Pires, M. V., & do Couto-Santos, F. R. (2020). Understanding farmers' perceptions and adaptation to climate change: the case of Rio das Contas basin, Brazil. *GeoJournal*, *85*, 805-821.

Central Statistics Agency (CSA). (2008). Summary and statistical report of the 2007 population and housing census. *Federal democratic republic of Ethiopia population census commission.* Addis Ababa (Ethiopia) UNFPA, Ethiopia

Central Statistics Agency (CSA). (2013). Population projection of Ethiopia for all regions at wereda level from 2014–2017. *Central Statistical Agency of Ethiopia*, *1*, 167-176.

Central Statistics Agency (CSA). (2018). Agricultural sample survey report on area and production of major crops (Private peasant holdings, Meher season 2017/2018 (2010 E.C.). The FDRE statistical bulletin, Volume I.

Challa, M., & Tilahun, U. (2014). Determinants and impacts of modern agricultural technology adoption in west Wollega: the case of Gulliso district. *Journal of Biology, Agriculture and Healthcare*, *4*(20), 63-77.

Chapman, A., Davies, W., Downey, C., & Dookie, D. (2021). ADB Climate Risk Country Profile: Micronesia.

Cheung, W. H., Senay, G. B., & Singh, A. (2008). Trends and spatial distribution of annual and seasonal rainfall in Ethiopia. *A Journal of the Royal Meteorological Society*, *28*(13), 1723-1734.

CIAT, U. (2017). Climate-Smart Agriculture in Ethiopia. CSA Country Profiles for Africa Series. *International Center for Tropical Agriculture (CIAT)*. *Washington, D.C.* Retrieved from https://hdl.handle.net/10568/92491.

Creswell, J. W., & Creswell, J. D. (2017). *Research design: Qualitative, quantitative, and mixed methods approaches*. Sage publications.

Crews, T. E., Carton, W., & Olsson, L. (2018). Is the future of agriculture perennial? Imperatives and opportunities to reinvent agriculture by shifting from annual monocultures to perennial polycultures. *Global Sustainability*, *1*, e11.

CRGE. (2011). Ethiopia's vision for a climate resilient green economy. *Addis Ababa, Ethiopia*, *28*.

Crippa, M., Solazzo, E., Guizzardi, D., Monforti-Ferrario, F., Tubiello, F. N., & Leip, A. J. N. F. (2021). Food systems are responsible for a third of global anthropogenic GHG emissions. *Nature Food*, *2*(3), 198-209.

Croppenstedt, A., Demeke, M., & Meschi, M. M. (2003). Technology adoption in the presence of constraints: the case of fertilizer demand in Ethiopia. *Review of Development Economics*, *7*(1), 58-70.

Dalton, P. S., Ghosal, S., & Mani, A. (2016). Poverty and aspirations failure. *The Economic Journal*, *126*(590), 165-188.

Dapilah, F., & Nielsen, J. Ø. (2020). Climate change extremes and barriers to successful adaptation outcomes: Disentangling a paradox in the semi-arid savanna zone of northern Ghana. *Ambio*, *49*, 1437-1449.

De Luis, M., Raventós, J., González-Hidalgo, J. C., Sánchez, J. R., & Cortina, J. (2000). Spatial analysis of rainfall trends in the region of Valencia (East Spain. *A Journal of the Royal Meteorological Society*, *20*(12), 1451-1469.

Debela, N., Mohammed, C., Bridle, K., Corkrey, R., & McNeil, D. (2015). Perception of climate change and its impact by smallholders in pastoral/agropastoral systems of Borana, South Ethiopia. *SpringerPlus*, *4*(1), 1-12.

Demalo, T. S. (2014). Farmers' Perception on Erosion Problem and Adoption of Soil and Water Conservation Structures (Unpublished Master's thesis): The Case of Ojoje Watershed in Doyogena Woreda. *Kembata Tembaro Zone*, Ethiopia.

Deressa, T. T., Hassan, R. M., & Ringler, C. (2011). Perception of and adaptation to climate change by farmers in the Nile basin of Ethiopia. *The Journal of Agricultural Science, 149*(1), 23-31.

Dhakal, C., Khadka, S., Park, C., & Escalante, C. L. (2022). Climate change adaptation and its impacts on farm income and downside risk exposure. *Resources, Environment and Sustainability*, *10*, 100082.

Di Falco, S., & Veronesi, M. (2018). Managing environmental risk in presence of climate change: the role of adaptation in the Nile Basin of Ethiopia. *Climate Smart Agriculture: Building Resilience to Climate Change*, 497-526.

DiPrete, T. A., & Gangl, M. (2004). Assessing bias in the estimation of causal effects: Rosenbaum bounds on matching estimators and instrumental variables estimation with imperfect instruments. *Sociological methodology*, *34*(1), 271-310.

Diro, G. T., Tompkins, A. M., & Bi, X. (2012). Dynamical downscaling of ECMWF Ensemble seasonal forecasts over East Africa with RegCM3. *Journal of Geophysical Research: Atmospheres*, *117*(D16).

Dowsing, M., & Cardey, S. (2020). Smallholder farmers' perspectives on Advisory Extension Services: A case study of the Gamo communities of southern Ethiopia. *Social Sciences*, *9*(9), 159.

Duan, P., Chen, S., Zhang, H., & Zhang, F. (2021). Grain for Green Project in farmers' minds: perceptions, aspirations and behaviors in eco-fragile region, Xinjiang, China. *International journal of climate change strategies and management*, *13*(2), 191-207.

Dubache, G., Ogwang, B. A., Ongoma, V., & Towfiqul Islam, A. R. M. (2019). The effect of Indian Ocean on Ethiopian seasonal rainfall. *Meteorology and Atmospheric Physics*, *131*, 1753-1761.

Dube, A. K., Fawole, W. O., Govindasamy, R., & ÖZKAN, B. (2019). Agricultural development led industrialization in Ethiopia: structural break analysis. *International Journal of Agriculture Forestry and Life Sciences*, *3*(1), 193-201.

Edenhofer, O. (Ed.). (2015). *Climate change 2014: mitigation of climate change* (Vol. 3). Cambridge University Press.

Engel, S., & Muller, A. (2016). Payments for environmental services to promote "climate-smart agriculture"? Potential and challenges. *Agricultural Economics*, *47*(S1), 173-184.

Erchafo, T. (2018). Economics of Enset (Ensete ventricosum) Cultivation and Constraints Faced by Cultivators in Doyogena District, SNNPR, Ethiopia. *Economics*, *40*.

Esayas, B., Simane, B., Teferi, E., Ongoma, V., & Tefera, N. (2019). Climate variability and farmers' perception in Southern Ethiopia. *Advances in Meteorology*, *2019*, 1-19.

Esayas, B., Simane, B., Teferi, E., Ongoma, V., & Tefera, N. (2018). Trends in extreme climate events over three agroecological zones of southern Ethiopia. *Advances in Meteorology*, *2018*, 1-17.

Etana, D., Snelder, D. J., van Wesenbeeck, C. F., & Buning, T. D. C. (2022). Climate change, in-situ adaptation, and migration decisions of smallholder farmers in central Ethiopia. *Migration and Development*, *11*(3), 737-761.

Etana, D., van Wesenbeeck, C. F., & de Cock Buning, T. (2021). Socio-cultural aspects of farmers' perception of the risk of climate change and variability in Central Ethiopia. *Climate and Development*, *13*(2), 139-151.

Fadina, A. M. R., & Barjolle, D. (2018). Farmers' adaptation strategies to climate change and their implications in the Zou Department of South Benin. *Environments*, *5*(1), 15.

FAO, F. (2010). Climate smart agriculture: policies, practices and financing for food security, adaptation and mitigation. *Food and Agriculture Organization. Rome, Italy*. http://www.fao.org/3/ i1881e/i1881e00.htm.

FAO. (2013). Sourcebook on Climate Smart Agriculture, Forestry and Fisheries.Rome, Italy. http://www. fao.org/climatechange/37491-0c425f2caa2f5e6f3b9162d39c8507fa3.pdf.

FAO. (2015). The impact of natural hazards and disasters on agriculture and food security and nutrition: A call for action to build resilient livelihoods. Food and Agriculture Organization of the United Nations. Rome, Italy.

FAO. (2016). Ethiopia climate-smart agriculture scoping study. *United Nations, FAO: Addis Ababa, Ethiopia*.

Fazzini, M., Bisci, C., & Billi, P. (2015). The climate of Ethiopia. *Landscapes and landforms of Ethiopia*, 65-87.

FDRE. (2019). Ethiopia's climate resilient green economy: National adaptation plan. *Addis Ababa, Ethiopia: Federal Democratic Republic of Ethiopia*.

Feliciano, D., Recha, J., Ambaw, G., MacSween, K., Solomon, D., & Wollenberg, E. (2022). Assessment of agricultural emissions, climate change mitigation and adaptation practices in Ethiopia. *Climate policy*, *22*(4), 427-444.

Feliciano, D., Recha, J., Ambaw, G., MacSween, K., Solomon, D., & Wollenberg, E. (2022). Assessment of agricultural emissions, climate change mitigation and adaptation practices in Ethiopia. *Climate policy*, *22*(4), 427-444.

Fentie, A., & Beyene, A. D. (2019). Climate-smart agricultural practices and welfare of rural smallholders in Ethiopia: Does planting method matter?. *Land use policy*, *85*, 387-396.

Feyissa, G., Zeleke, G., Bewket, W., & Gebremariam, E. (2018). Downscaling of future temperature and precipitation extremes in Addis Ababa under climate change. *Climate*, *6*(3), 58.

Field, C. B., & Barros, V. R. (Eds.). (2014). *Climate change 2014–Impacts, adaptation and vulnerability: Regional aspects*. Cambridge University Press.

Fierros-González, I., & Lopez-Feldman, A. (2021). Farmers' perception of climate change: A review of the literature for Latin America. *Frontiers in Environmental Science*, *9*, 672399.

Funk, C., Peterson, P., Landsfeld, M., Pedreros, D., Verdin, J., Shukla, S., Husak, G., Rowland, J., Harrison, L., Hoell, A. and Michaelsen, J. (2015). The climate hazards infrared precipitation with stations—a new environmental record for monitoring extremes. *Scientific data*, *2*(1), 1-21.

Fusco, G. (2022). Climate Change and food security in the northern and eastern African regions: a panel data analysis. *Sustainability*, *14*(19), 12664.

Gashaw, T., Mebrat, W., Hagos, D., & Nigussie, A. (2014). Climate change adaptation and mitigation measures in Ethiopia. *Journal of Biology, Agriculture and Healthcare*, *4*(15), 148-152.

Gebrechorkos, S. H., Hülsmann, S., & Bernhofer, C. (2019). Changes in temperature and precipitation extremes in Ethiopia, Kenya, and Tanzania. *International Journal of Climatology*, *39*(1), 18-30.

Gebregiorgis, D., Rayner, D., & Linderholm, H. W. (2019). Does the IOD independently influence seasonal monsoon patterns in Northern Ethiopia?. *Atmosphere*, *10*(8), 432.

Gebrehiwot, T., & Van Der Veen, A. (2013). Farm level adaptation to climate change: the case of farmer's in the Ethiopian Highlands. *Environmental management*, *52*(1), 29-44.

Gebremicael, T. G., Mohamed, Y. A., & Hagos, E. Y. (2017). Temporal and spatial changes of rainfall and streamflow in the Upper Tekezē–Atbara river basin, Ethiopia. *Hydrology and Earth System Sciences*, *21*(4), 2127-2142.

Gemeda, D. O., Feyssa, D. H., & Garedew, W. (2021). Meteorological data trend analysis and local community perception towards climate change: a case study of Jimma City, Southwestern Ethiopia. *Environment, Development and Sustainability*, *23*, 5885-5903.

Genicot, G., & Ray, D. (2017). Aspirations and inequality. *Econometrica*, *85*(2), 489-519.

Gidey, E., Dikinya, O., Sebego, R., Segosebe, E., & Zenebe, A. (2018). Modeling the spatio-temporal meteorological drought characteristics using the standardized precipitation index (SPI) in raya and its environs, northern Ethiopia. *Earth Systems and Environment*, *2*, 281-292.

Girma, E., Tino, J., and Wayessa, G. (2016). Rainfall trend and variability analysis in Setema-Gatira area of Jimma, Southwestern Ethiopia. *African Journal of Agricultural Research*, *11*(32), 3037-3045.

Girma, M., Jerneck, A., & Dejen, A. (2023). Food insecurity experience during climate shock periods and farmers' aspiration in Ethiopia. *Environmental Development*, *46*, 100868.

Gissila, T., Black, E., Grimes, D. I. F., & Slingo, J. M. (2004). Seasonal forecasting of the Ethiopian summer rains. *International Journal of Climatology*, *24*(11), 1345-1358.

Gitz, V., Meybeck, A., Lipper, L., Young, C. D., & Braatz, S. (2016). Climate change and food security: risks and responses. *Food and Agriculture Organization of the United Nations (FAO) Report*, *110*(2).

Gleixner, S., Keenlyside, N., Viste, E., & Korecha, D. (2017). The El Niño effect on Ethiopian summer rainfall. *Climate Dynamics*, *49*, 1865-1883.

Gocic, M., & Trajkovic, S. (2013). Analysis of changes in meteorological variables using Mann-Kendall and Sen's slope estimator statistical tests in Serbia. *Global and planetary change*, *100*, 172-182.

Greene, W. H., & Hensher, D. A. (2003). A latent class model for discrete choice analysis: contrasts with mixed logit. *Transportation Research Part B: Methodological*, *37*(8), 681-698.

Habiyaremye, A. (2017). Estimating the impact of sericulture adoption on farmer income in Rwanda: an application of propensity score matching. *Agrekon*, *56*(3), 296-311.

Hänsel, S., Schucknecht, A., & Matschullat, J. (2016). The Modified Rainfall Anomaly Index (mRAI)—is this an alternative to the Standardised Precipitation Index (SPI) in evaluating future extreme precipitation characteristics?. *Theoretical and applied climatology*, *123*, 827-844.

Hare, W. (2003). Assessment of knowledge on impacts of climate change–contribution. *Arctic*, *100*(6).

Heckman, J. J. (1976). The common structure of statistical models of truncation, sample selection and limited dependent variables and a simple estimator for such models. In *Annals of economic and social measurement, volume 5, number 4* (pp. 475-492). NBER.

Heckman, J., & Navarro-Lozano, S. (2004). Using matching, instrumental variables, and control functions to estimate economic choice models. *Review of Economics and statistics*, *86*(1), 30-57.

Hellin, J., Fisher, E., Balié, J., Sander, B. O., & Kohli, A. (2021). Scaling Climate-Smart Agriculture Through Interdisciplinary Research-for-Development: Learning from South and Southeast Asia's Rice-Based Systems. In *Handbook of Climate Change Management: Research, Leadership, Transformation* (pp. 1187-1202). Cham: Springer International Publishing.

Henriksson, R., Vincent, K., Archer, E., & Jewitt, G. (2021). Understanding gender differences in availability, accessibility and use of climate information among smallholder farmers in Malawi. *Climate and Development*, *13*(6), 503-514.

Hilemelekot, F., Ayal, D. Y., Ture, K., & Zeleke, T. T. (2021). Climate change and variability adaptation strategies and their implications for household food Security: the case of Basona Worena District, North Shewa zone, Ethiopia. *Climate Services*, *24*, 100269.

Hoben, A. (1995). Paradigms and politics: the cultural construction of environmental policy in Ethiopia. *World Development*, *23*(6), 1007-1021.

Hoffmann, I. (2013). Adaptation to climate change–exploring the potential of locally adapted breeds. *Animal*, *7*(s2), 346-362.

Hoffmann, I. (2013). Adaptation to climate change–exploring the potential of locally adapted breeds. *Animal*, *7*(s2), 346-362.

Howe, P. D., Marlon, J. R., Mildenberger, M., & Shield, B. S. (2019). How will climate change shape climate opinion?. *Environmental Research Letters*, *14*(11), 113001.

Hundera, H., Mpandeli, S., & Bantider, A. (2019). Smallholder farmers' awareness and perceptions of climate change in Adama district, central rift valley of Ethiopia. *Weather and Climate Extremes*, *26*, 100230.

Huong, N., Shun Bo, Y., & Fahad, S. (2017). Farmers' perception, awareness and adaptation to climate change: evidence from northwest Vietnam. *International Journal of Climate Change Strategies and Management*, *9*(4), 555-576.

Hussain, S., Amin, A., Mubeen, M., Khaliq, T., Shahid, M., Hammad, H.M., Sultana, S.R., Awais, M., Murtaza, B., Amjad, M. and Fahad, S. (2022). Climate smart agriculture (CSA) technologies. *Building Climate Resilience in Agriculture: Theory, Practice and Future Perspective*, 319-338.

Hyland, J. J., Jones, D. L., Parkhill, K. A., Barnes, A. P., & Williams, A. P. (2016). Farmers' perceptions of climate change: identifying types. *Agriculture and Human Values*, *33*, 323-339.

IPCC. (2014). *Climate Change 2014.* Impacts, adaptation and vulnerability. *Part A: global and sectoral aspects. Contribution of working group II to the fifth assessment report of the intergovernmental Panel on Climate Change*, *1132*. Cambridge University Press.

IPCC. (2022). Summary for Policymakers: Climate change 2022: Impacts, adaptation and vulnerability. *Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel of Climate Change*. Cambridge University Press.

Islam, R., Schech, S., & Saikia, U. (2021). Climate change events in the Bengali migration to the Chittagong Hill Tracts (CHT) in Bangladesh. *Climate and Development*, *13*(5), 375-385.

Issahaku, G., & Abdulai, A. (2020). Adoption of climate-smart practices and its impact on farm performance and risk exposure among smallholder farmers in Ghana. *Australian Journal of Agricultural and Resource Economics*, *64*(2), 396-420.

Jaeger, M. M. (2007). Economic and social returns to educational choices: Extending the utility function. *Rationality and Society*, *19*(4), 451-483.

Janzen, S. A., Magnan, N., Sharma, S., & Thompson, W. M. (2017). Aspirations failure and formation in rural Nepal. *Journal of Economic Behavior & Organization*, *139*, 1-25.

Jellason, N. P., Conway, J. S., & Baines, R. N. (2021). Understanding impacts and barriers to adoption of climate-smart agriculture (CSA) practices in North-Western Nigerian drylands. *The Journal of Agricultural Education and Extension*, *27*(1), 55-72.

Jellason, N. P., N. Baines, R., S. Conway, J., & Ogbaga, C. C. (2019). Climate change perceptions and attitudes to smallholder adaptation in Northwestern Nigerian Drylands. *Social Sciences*, *8*(2), 31.

Jellason, N. P., Salite, D., Conway, J. S., & Ogbaga, C. C. (2022). A systematic review of smallholder farmers' climate change adaptation and enabling conditions for knowledge integration in Sub-Saharan African (SSA) drylands. *Environmental Development*, 100733.

Jethi, R., Joshi, K., & Chandra, N. (2016). Toward climate change and community-based adaptation-mitigation strategies in hill agriculture. *Conservation Agriculture: An Approach to Combat Climate Change in Indian Himalaya*, 185-202.

Jha, C. K., & Gupta, V. (2021). Do better agricultural extension and climate information sources enhance adaptive capacity? A micro-level assessment of farm households in rural India. *Ecofeminism and Climate Change*, *2*(2), 83-102.

Jha, C. K., & Gupta, V. (2021). Farmer's perception and factors determining the adaptation decisions to cope with climate change: An evidence from rural India. *Environmental and Sustainability Indicators*, *10*, 100112.

Jho, H., Yoon, H. G., & Kim, M. (2014). The relationship of science knowledge, attitude and decision making on socio-scientific issues: The case study of students' debates on a nuclear power plant in Korea. *Science & Education*, *23*, 1131-1151.

Jiri, O., Mafongoya, P. L., & Leal Filho, W. (2018). Managing vulnerability to drought and enhancing smallholder farmers resilience to climate change risks in Zimbabwe. *Handbook of climate change resilience*, 1-17.

Jury, M. R. (2010). Ethiopian decadal climate variability. *Theoretical and Applied Climatology*, *101*, 29-40.

Kalimba, U. B., & Culas, R. J. (2020). Climate change and farmers' adaptation: Extension and capacity building of smallholder farmers in Sub-Saharan Africa. *Global Climate Change and Environmental Policy: Agriculture Perspectives*, 379-410.

Kangogo, D., Dentoni, D., & Bijman, J. (2021). Adoption of climate-smart agriculture among smallholder farmers: Does farmer entrepreneurship matter?. *Land Use Policy*, *109*, 105666.

Kanu, I. M., & Okezie, A. C. (2021). Income distribution pattern among cocoa farmers in Abia State, Nigeria: The lorenze curve and mean per capita household expenditure approach. *International Journal of Agriculture Forestry and Life Sciences*, *5*(1), 21-28.

Karabulut, M. (2015). Drought analysis in Antakya-Kahramanmaraş Graben, Turkey. *Journal of Arid Land*, *7*, 741-754.

Karimi, A. H., Von Kügelgen, J., Schölkopf, B., & Valera, I. (2020). Algorithmic recourse under imperfect causal knowledge: a probabilistic approach. *Advances in neural information processing systems*, *33*, 265-277.

Kasie, T. A., Demissie, B. S., Bahry, M. J., Gessesse, G. M., & Wale, L. E. (2020). The impact of the 2015 El Niño-induced drought on household consumption: Evidence from rural Ethiopia. *Climate and Development*, *12*(9), 854-863.

Kassaye, A. Y., Shao, G., Wang, X., & Belete, M. (2022). Evaluating the practices of climate-smart agriculture sustainability in Ethiopia using geocybernetic assessment matrix. *Environment, Development and Sustainability*, *24*(1), 724-764.

Kassie, B. T., Asseng, S., Rotter, R. P., Hengsdijk, H., Ruane, A. C., & Van Ittersum, M. K. (2015). Exploring climate change impacts and adaptation options for maize production in the Central Rift Valley of Ethiopia using different climate change scenarios and crop models. *Climatic Change, 129*(1), 145-158.

kebede, D., Emanna, B., & Tesfay, G. (2022). Impact of land acquisition for large-scale agricultural investments on vulnerability of displaced households to climate change shocks in Ethiopia. *Ecosystems and People*, *18*(1), 2143572.

Keeley, J., & Scoones, I. (2000). Knowledge, power and politics: the environmental policy-making process in Ethiopia. *The Journal of Modern African Studies*, *38*(1), 89-120.

Kendall, M. G. (1975). Rank Correlation Methods. London: Charles Griffin and Co. In: Ltd.

Keshavarz, M., & Moqadas, R. S. (2021). Assessing rural households' resilience and adaptation strategies to climate variability and change. *Journal of Arid Environments*, *184*, 104323.

Khan, N. A., Qiao, J., Abid, M., & Gao, Q. (2021). Understanding farm-level cognition of and autonomous adaptation to climate variability and associated factors: Evidence from the rice-growing zone of Pakistan. *Land Use Policy*, *105*, 105427.

Khatri-Chhetri, A., Aggarwal, P. K., Joshi, P. K., & Vyas, S. (2017). Farmers' prioritization of climate-smart agriculture (CSA) technologies. *Agricultural systems*, *151*, 184-191.

Khatri-Chhetri, A., Aryal, J. P., Sapkota, T. B., & Khurana, R. (2016). Economic benefits of climate-smart agricultural practices to smallholder farmers in the Indo-Gangetic Plains of India. *Current Science*, 1251-1256.

Khonje, M. G., Manda, J., Mkandawire, P., Tufa, A. H., & Alene, A. D. (2018). Adoption and welfare impacts of multiple agricultural technologies: evidence from eastern Zambia. *Agricultural Economics*, *49*(5), 599-609.

Khonje, M., Manda, J., Alene, A. D., & Kassie, M. (2015). Analysis of adoption and impacts of improved maize varieties in eastern Zambia. *World development*, *66*, 695-706.

Khoza, S., de Beer, L. T., van Niekerk, D., & Nemakonde, L. (2021). A gender-differentiated analysis of climate-smart agriculture adoption by smallholder farmers: Application of the extended technology acceptance model. *Gender, Technology and Development*, *25*(1), 1-21.

Kimaro, A.A., Mpanda, M., Rioux, J., Aynekulu, E., Shaba, S., Thiong'o, M., Mutuo, P., Abwanda, S., Shepherd, K., Neufeldt, H. and Rosenstock,T. S. (2016). Is conservation agriculture 'climate-smart'for maize farmers in the highlands of Tanzania? *Nutrient cycling in agroecosystems*, *105*, 217-228

Knapp, L., Wuepper, D., & Finger, R. (2021). Preferences, personality, aspirations, and farmer behavior. *Agricultural Economics*, *52*(6), 901-913.

Koch, O., Ibisch, P. L., & Bloch, R. (2022). Climate change and shifting land-use: Consequences for smallholder agroforestry systems and rural livelihoods in the southwest Ethiopian Highlands. *Agroecology and Sustainable Food Systems*, *46*(5), 672-711.

Kogo, B. K., Kumar, L., & Koech, R. (2021). Climate change and variability in Kenya: a review of impacts on agriculture and food security. *Environment, Development and Sustainability*, *23*, 23-43.

Koudahe, K., Kayode, A. J., Samson, A. O., Adebola, A. A., & Djaman, K. (2017). Trend analysis in standardized precipitation index and standardized anomaly index in the context of climate change in Southern Togo. *Atmospheric and Climate Sciences*, *7*(04), 401.

Kristjanson, P., Bryan, E., Bernier, Q., Twyman, J., Meinzen-Dick, R., Kieran, C., Ringler, C., Jost, C. and Doss, C. (2017). Addressing gender in agricultural research for development in the face of a changing climate: where are we and where should we be going?. *International Journal of Agricultural Sustainability*, *15*(5), 482-500.

Kumar, U., Werners, S. E., Paparrizos, S., Datta, D. K., & Ludwig, F. (2021). Co-producing climate information services with smallholder farmers in the Lower Bengal Delta: How forecast visualization and communication support farmers' decision-making. *Climate Risk Management*, *33*, 100346.

Kurgat, B. K., Lamanna, C., Kimaro, A., Namoi, N., Manda, L., & Rosenstock, T. S. (2020). Adoption of climate-smart agriculture technologies in Tanzania. *Frontiers in sustainable food systems*, *4*, 55.

Lafore, T., Kibamo, B., Ergicho, K., & Ezo, E. (2021). Client Satisfaction towards Expanded Program on Immunization Service and Associated Factors in Doyogena Woreda, Southern Ethiopia. https://kspublisher.com/media/articles/MERJN_11_21-30_MqvwCFC.pdf

Leal Filho, W., Balogun, A.L., Ayal, D.Y., Bethurem, E.M., Murambadoro, M., Mambo, J., Taddese, H., Tefera, G.W., Nagy, G.J., Fudjumdjum, H. and Mugabe, P. (2018). Strengthening climate change adaptation capacity in Africa-case studies from six major African cities and policy implications. *Environmental Science & Policy*, *86*, 29-37.

Leisner, C. P. (2020). Climate change impacts on food security-focus on perennial cropping systems and nutritional value. *Plant Science*, *293*, 110412.

Leta, G., Kelboro, G., Stellmacher, T., & Hornidge, A. K. (2017). The agricultural extension system in Ethiopia: operational setup, challenges and opportunities. https://www.econstor.eu/handle/10419/187464.

Lewis, K. (2017). Understanding climate as a driver of food insecurity in Ethiopia. *Climatic Change*, *144*, 317-328.

Li, H. C., Hsiao, Y. H., Chang, C. W., Chen, Y. M., & Lin, L. Y. (2021). Agriculture adaptation options for flood impacts under climate change—A simulation analysis in the Dajia River Basin. *Sustainability*, *13*(13), 7311.

Lipper, L., McCarthy, N., Zilberman, D., Asfaw, S., & Branca, G. (2017). *Climate smart agriculture: building resilience to climate change* (p. 630). Springer Nature. DOI:10.1007/978-3-319-61194-5

Lipper, L., Thornton, P., Campbell, B.M., Baedeker, T., Braimoh, A., Bwalya, M., Caron, P., Cattaneo, A., Garrity, D., Henry, K. and Hottle, R. (2014). Climate-smart agriculture for food security. *Nature climate change*, *4*(12), 1068-1072.

Lobell, D. B., & Gourdji, S. M. (2012). The influence of climate change on global crop productivity. *Plant physiology*, *160*(4), 1686-1697.

Lunduka, R. W., Mateva, K. I., Magorokosho, C., & Manjeru, P. (2019). Impact of adoption of drought-tolerant maize varieties on total maize production in south Eastern Zimbabwe. *Climate and development*, *11*(1), 35-46.

Maddison, D. (2006). Environmental Kuznets curves: A spatial econometric approach. *Journal of Environmental Economics and management*, *51*(2), 218-230.

Maina, K. W., Ritho, C. N., Lukuyu, B. A., & Rao, E. J. O. (2020). Socio-economic determinants and impact of adopting climate-smart Brachiaria grass among dairy farmers in Eastern and Western regions of Kenya. *Heliyon*, *6*(6).

Maina, K., Ritho, C., Lukuyu, B. A., & Rao, E. J. O. (2019). Determinants and impact of adopting climate-smart brachiaria grass among dairy farmers in Kenya. https://hdl.handle.net/10568/101920.

Mairura, F.S., Musafiri, C.M., Kiboi, M.N., Macharia, J.M., Ng'etich, O.K., Shisanya, C.A., Okeyo, J.M., Mugendi, D.N., Okwuosa, E.A. and Ngetich, F.K. (2021). Determinants of farmers' perceptions of climate variability, mitigation, and adaptation strategies in the central highlands of Kenya. *Weather and Climate Extremes*, *34*, 100374.

Makate, C. (2019). Effective scaling of climate smart agriculture innovations in African smallholder agriculture: A review of approaches, policy and institutional strategy needs. *Environmental science & policy*, *96*, 37-51.

Makate, C., Makate, M., Mango, N., & Siziba, S. (2019). Increasing resilience of smallholder farmers to climate change through multiple adoption of proven climate-smart agriculture innovations. Lessons from Southern Africa. *Journal of environmental management*, *231*, 858-868.

Makate, C., Wang, R., Makate, M., & Mango, N. (2016). Crop diversification and livelihoods of smallholder farmers in Zimbabwe: adaptive management for environmental change. *SpringerPlus*, *5*, 1-18.

Makate, C., Wang, R., Makate, M., & Mango, N. (2017). Impact of drought tolerant maize adoption on maize productivity, sales and consumption in rural Zimbabwe. *Agrekon*, *56*(1), 67-81.

Mall, R. K., Gupta, A., Singh, R., Singh, R. S., & Rathore, L. S. (2006). Water resources and climate change: An Indian perspective. *Current science*, 1610-1626.

Mango, N., Siziba, S., & Makate, C. (2017). The impact of adoption of conservation agriculture on smallholder farmers' food security in semi-arid zones of southern Africa. *Agriculture & Food Security*, *6*, 1-8.

Mann, H. B. (1945). Nonparametric tests against trend. *Econometrica: Journal of the econometric society*, 245-259.

Marie, M., Yirga, F., Haile, M., & Tquabo, F. (2020). Farmers' choices and factors affecting adoption of climate change adaptation strategies: evidence from northwestern Ethiopia. *Heliyon*, *6*(4).

Mariye, M., Jianhua, L., & Maryo, M. (2022). Land use and land cover change, and analysis of its drivers in Ojoje watershed, Southern Ethiopia. *Heliyon*, *8*(4).

Marra, M., Pannell, D. J., & Ghadim, A. A. (2003). The economics of risk, uncertainty and learning in the adoption of new agricultural technologies: where are we on the learning curve? *Agricultural systems*, *75*(2-3), 215-234.

Mase, A. S., Gramig, B. M., & Prokopy, L. S. (2017). Climate change beliefs, risk perceptions, and adaptation behavior among Midwestern US crop farmers. *Climate Risk Management*, *15*, 8-17.

Massresha, S. E., Lema, T. Z., Neway, M. M., & Degu, W. A. (2021). Perception and determinants of agricultural technology adoption in north shoa zone, Amhara regional state, Ethiopia. *Cogent Economics & Finance*, *9*(1), 1956774.

Matewos, T. (2019). Climate change-induced impacts on smallholder farmers in selected districts of Sidama, Southern Ethiopia. *Climate*, *7*(5), 70.

Matewos, T. (2020). The state of local adaptive capacity to climate change in drought-prone districts of rural Sidama, southern Ethiopia. *Climate Risk Management*, *27*, 100209.

Mathewos, T., Temesgen, D., Hamza, D., & Fesseha, H. (2021). Determinants of smallholder farmers' participation in improved sheep production: The case of Doyogena District, Kembata Tembaro Zone, Southern Ethiopia. *Advances in Agriculture*, *2021*, 1-17.

Matthews, H. D., Zickfeld, K., Knutti, R., & Allen, M. R. (2018). Focus on cumulative emissions, global carbon budgets and the implications for climate mitigation targets. *Environmental Research Letters*, *13*(1), 010201.

Mavhura, E., Manyangadze, T., & Aryal, K. R. (2022). Perceived impacts of climate variability and change: an exploration of farmers' adaptation strategies in Zimbabwe's intensive farming region. *Geojournal*, *87*(5), 3669-3684.

Maxwell, D., Vaitla, B., & Coates, J. (2014). How do indicators of household food insecurity measure up? An empirical comparison from Ethiopia. *Food policy*, *47*, 107-116.

McKee, T. B., Doesken, N. J., & Kleist, J. (1993, January). The relationship of drought frequency and duration to time scales. In *Proceedings of the 8th Conference on Applied Climatology* (Vol. 17, No. 22, pp. 179-183).

McNaught, R., Warrick, O., & Cooper, A. (2014). Communicating climate change for adaptation in rural communities: a Pacific study. *Regional Environmental Change*, *14*, 1491-1503.

Megersa, B., Markemann, A., Angassa, A., Ogutu, J. O., Piepho, H. P., & Zaráte, A. V. (2014). Impacts of climate change and variability on cattle production in southern Ethiopia: Perceptions and empirical evidence. *Agricultural systems*, *130*, 23-34.

Mehiriz, K., & Gosselin, P. (2022). The Effect of perceived threats and response efficacy on adaptation to smog: An instrumental variables design. *Risk Analysis*, *42*(5), 1042-1055.

Mekasha, A., Tesfaye, K., & Duncan, A. J. (2014). Trends in daily observed temperature and precipitation extremes over three Ethiopian eco-environments. *International Journal of Climatology*, *34*(6), 1990-1999.

Mekonen, A. A., Berlie, A. B., & Ferede, M. B. (2020). Spatial and temporal drought incidence analysis in the northeastern highlands of Ethiopia. *Geoenvironmental Disasters*, *7*, 1-17.

Mekonnen, A., Tessema, A., Ganewo, Z., & Haile, A. (2021). Climate change impacts on household food security and adaptation strategies in southern Ethiopia. *Food and Energy Security*, *10*(1), e266.

Mekonnen, Z., Kidemu, M., Abebe, H., Semere, M., Gebreyesus, M., Worku, A., Tesfaye, M. and Chernet, A.(2021). Traditional knowledge and institutions for sustainable climate change adaptation in Ethiopia. *Current Research in Environmental Sustainability*, *3*, 100080.

Mekuyie, M., & Mulu, D. (2021). Perception of impacts of climate variability on pastoralists and their adaptation/coping strategies in fentale district of Oromia region, Ethiopia. *Environmental Systems Research*, *10*, 1-10.

Melketo, T. A., Geta, E., & Sieber, S. (2020). Understanding livelihood diversification patterns among smallholder farm households in Southern Ethiopia. *Sustainable Agriculture Research*, *9*(526-2020-563), 26-41.

Mengistu, A., Kebede, G., Feyissa, F., & Assefa, G. (2017). Review on major feed resources in Ethiopia: Conditions, challenges and opportunities. *Academic Research Journal of Agricultural Science and Research*, *5*(3), 176-185.

Mengistu, D., Bewket, W., & Lal, R. (2014). Recent spatiotemporal temperature and rainfall variability and trends over the Upper Blue Nile River Basin, Ethiopia. *International Journal of Climatology*, *34*(7), 2278-2292.

Mercer, D. E. (2004). Adoption of agroforestry innovations in the tropics: a review. *Agroforestry systems, 61*(1), 311-32

Mersha, A. A., & van Laerhoven, F. (2018). The interplay between planned and autonomous adaptation in response to climate change: Insights from rural Ethiopia. *World Development*, *107*, 87-97.

Mesfin, D., Simane, B., Belay, A., Recha, J. W., & Schmiedel, U. (2020). Assessing the adaptive capacity of households to climate change in the Central Rift Valley of Ethiopia. *Climate*, *8*(10), 106.

Minda, T. T., van der Molen, M. K., Struik, P. C., Combe, M., Jiménez, P. A., Khan, M. S., & de Arellano, J. V. G. (2018). The combined effect of elevation and meteorology on potato crop dynamics: a 10-year study in the Gamo Highlands, Ethiopia. *Agricultural and Forest Meteorology*, *262*, 166-177.

Minot, N., Warner, J., Dejene, S., & Zewdie, T. (2021). Agricultural commercialization in Ethiopia: results from the analysis of panel household data. *AgEcon Search. https://ageconsearch.umn.edu/record/315314?v=pdf.*

Mirzabaev, A. (2018). Improving the resilience of central asian agriculture to weather variability and climate change. *Climate smart agriculture: building resilience to climate change*, 477-495.

Morton, J. F. (2007). The impact of climate change on smallholder and subsistence agriculture. *Proceedings of the national academy of sciences*, *104*(50), 19680-19685.

Mota, A. A., Lachore, S. T., & Handiso, Y. H. (2019). Assessment of food insecurity and its determinants in the rural households in Damot Gale Woreda, Wolaita zone, southern Ethiopia. *Agriculture & Food Security*, *8*(1), 1-11.

Mugabe, P. A. (2020). Assessment of information on successful climate-smart agricultural practices/innovations in Tanzania. *Handbook of climate change resilience*, 2721-2741

Mujeyi, A. (2018). Policy and institutional dimensions in climate-smart agriculture adoption: case of rural communities in Zimbabwe. *Handbook of climate change resilience*, *2018*.

Mujeyi, A., Mudhara, M., & Mutenje, M. (2021). The impact of climate smart agriculture on household welfare in smallholder integrated crop–livestock farming systems: evidence from Zimbabwe. *Agriculture & Food Security*, *10*(1), 1-15.

Musafiri, C. M., Kiboi, M., Macharia, J., Ng'etich, O. K., Kosgei, D. K., Mulianga, B., ... & Ngetich, F. K. (2022). Adoption of climate-smart agricultural practices among smallholder farmers in Western Kenya: do socioeconomic, institutional, and biophysical factors matter?. *Heliyon*, *8*(1).

Mvula, A., & Dixon, A. (2021). Farmer experiences of Tiyeni's 'deep-bed farming'conservation agriculture system in Malawi. *Agroecology and Sustainable Food Systems*, *45*(2), 175-196.

Mwongera, C., Shikuku, K.M., Twyman, J., Läderach, P., Ampaire, E., Van Asten, P., Twomlow, S. and Winowiecki, L.A. (2017). Climate smart agriculture rapid appraisal (CSA-RA): A tool for prioritizing context-specific climate smart agriculture technologies. *Agricultural systems*, *151*, 192-203.

Mwungu, C. M., Mwongera, C., Shikuku, K. M., Acosta, M., & Läderach, P. (2018). Determinants of adoption of climate-smart agriculture technologies at farm plot level: an assessment from southern Tanzania. https://link.springer.com/referenceworkentry/10.1007/978-3-319-71025-9_78-1.

Nandi, R., & Nedumaran, S. (2021). Understanding the aspirations of farming communities in developing countries: a systematic review of the literature. *The European Journal of Development Research*, *33*(4), 809-832.

National Meteorological Agency. (2007). Climate change national adaptation programme of action (Napa) of Ethiopia. *National Meteorological Services Agency, Ministry of Water Resources, Federal Democratic Republic of Ethiopia, Addis Ababa*.

Ng, T. L. (2010). *Response of farmers' decisions and stream water quality to price incentives for nitrogen reduction, carbon abatement, and miscanthus cultivation: Predictions based on agent-based modeling coupled with water quality modeling* (Doctoral dissertation, University of Illinois).

Ngoma, H., Pelletier, J., Mulenga, B. P., & Subakanya, M. (2021). Climate-smart agriculture, cropland expansion and deforestation in Zambia: Linkages, processes and drivers. *Land Use Policy*, *107*, 105482.

Nguyen, T. P. L., Seddaiu, G., & Roggero, P. P. (2019). Declarative or procedural knowledge? Knowledge for enhancing farmers' mitigation and adaptation behaviour to climate change. *Journal of Rural Studies*, *67*, 46-56.

Nhemachena, C., & Hassan, R. (2007). *Micro-level analysis of farmers adaption to climate change in Southern Africa*. Intl Food Policy Res Inst.

Njeru, E., Grey, S., & Kilawe, E. (2016). Eastern Africa climate-smart agriculture scoping study: Ethiopia, Kenya and Uganda. *FAO, Addis Ababa, Ethiopia*.

Nyang'au, J. O., Mohamed, J. H., Mango, N., Makate, C., & Wangeci, A. N. (2021). Smallholder farmers' perception of climate change and adoption of climate smart agriculture practices in Masaba South Sub-county, Kisii, Kenya. *Heliyon*, *7*(4).

Nyasimi, M., Kimeli, P., Sayula, G., Radeny, M., Kinyangi, J., & Mungai, C. (2017). Adoption and dissemination pathways for climate-smart agriculture technologies and practices for climate-resilient livelihoods in Lushoto, Northeast Tanzania. *Climate*, *5*(3), 63.

Nyirahabimana, H., Turinawe, A., Lederer, J., Karungi, J., & Herrnegger, M. (2021). What influences farmer's adoption lag for soil and water conservation practices? Evidence from Sio-Malaba Malakisi River Basin of Kenya and Uganda borders. *Agronomy*, *11*(10), 1985.

Obeng, E., Akponikpe, P., and Adiku, S. (2013). Considering effective adaptation options to impacts of climate change for maize production in Ghana. *Environmental Development*, *5*, 131-145.

Ogada, M. J., Rao, E. J., Radeny, M., Recha, J. W., & Solomon, D. (2020). Climate-smart agriculture, household income and asset accumulation among smallholder farmers in the Nyando basin of Kenya. *World Development Perspectives*, *18*, 100203.

Ogundeji, A. A. (2022). Adaptation to climate change and impact on smallholder farmers' food security in South Africa. *Agriculture*, *12*(5), 589.

Ogunyiola, A., Gardezi, M., & Vij, S. (2022). Smallholder farmers' engagement with climate smart agriculture in Africa: role of local knowledge and upscaling. *Climate Policy*, *22*(4), 411-426.

Ogunyiola, A., Gardezi, M., & Vij, S. (2022). Smallholder farmers' engagement with climate smart agriculture in Africa: role of local knowledge and upscaling. *Climate Policy*, 1-16.

Ojara, M. A., Yunsheng, L., Ongoma, V., Mumo, L., Akodi, D., Ayugi, B., & Ogwang, B. A. (2021). Projected changes in East African climate and its impacts on climatic suitability of maize production areas by the mid-twenty-first century. *Environmental Monitoring and Assessment*, *193*, 1-24.

Ojo, T. O., & Baiyegunhi, L. J. S. (2020). Determinants of climate change adaptation strategies and its impact on the net farm income of rice farmers in south-west Nigeria. *Land Use Policy*, *95*, 103946.

Ojoko, E. A., Akinwunmi, J. A., Yusuf, S. A., & Oni, O. A. (2017). Factors influencing the level of use of climate-smart agricultural practices (CSAPs) in Sokoto state, Nigeria. *Journal of Agricultural Sciences (Belgrade)*, *62*(3), 315-327.

Oliver, J. E. (1980). Monthly precipitation distribution: a comparative index. *The Professional Geographer*, *32*(3), 300-309.

Omilola, B., & Robele, S. (2017). *The Central position of agriculture within the 2030 Agenda for sustainable development* (Vol. 1683). Intl Food Policy Res Inst.

Onyeneke, R. U., Igberi, C. O., Uwadoka, C. O., & Aligbe, J. O. (2018). Status of climate-smart agriculture in southeast Nigeria. *GeoJournal*, *83*, 333-346.

Onyutha, C. (2019). African food insecurity in a changing climate: The roles of science and policy. *Food and Energy Security*, *8*(1), e00160.

Ouédraogo, M., Houessionon, P., Zougmoré, R. B., & Partey, S. T. (2019). Uptake of climate-smart agricultural technologies and practices: Actual and potential adoption rates in the climate-smart village site of Mali. *Sustainability*, *11*(17), 4710.

Owusu, K., Obour, P. B., & Asare-Baffour, S. (2015). Climate variability and climate change impacts on smallholder farmers in the Akuapem North District, Ghana. *Handbook of climate change adaptation*, 1791-1806.

Palanisami, K., Kumar, D. S., Malik, R. P. S., Raman, S., Kar, G., & MOHAN, K. (2015). Managing water management research: analysis of four decades of research and outreach programmes in India. *Economic and Political Weekly*, 33-43.

Pamuk, H., Asseldonk, M. V., Wattel, C., Ng'ang'a, S. K., Hella, J. P., & Ruben, R. (2021). Farmer Field Business Schools and Village Savings and Loan Associations for promoting climate-smart agriculture practices: Evidence from rural Tanzania. *CGIAR Research Program on Climate Change, Agriculture and Food Security Working Paper*.

Partey, S. T., Zougmoré, R. B., Ouédraogo, M., & Campbell, B. M. (2018). Developing climate-smart agriculture to face climate variability in West Africa: Challenges and lessons learnt. *Journal of cleaner Production*, *187*, 285-295.

Paul, C. J., & Weinthal, E. (2019). The development of Ethiopia's Climate Resilient Green Economy 2011–2014: implications for rural adaptation. *Climate and Development*, *11*(3), 193-202.

Pedersen, J. S. T., Santos, F. D., van Vuuren, D., Gupta, J., Coelho, R. E., Aparício, B. A., & Swart, R. (2021). An assessment of the performance of scenarios against historical global emissions for IPCC reports. *Global Environmental Change*, *66*, 102199.

Philip, S., Kew, S.F., Jan van Oldenborgh, G., Otto, F., O'Keefe, S., Haustein, K., King, A., Zegeye, A., Eshetu, Z., Hailemariam, K. and Singh, R. (2018). Attribution analysis of the Ethiopian drought of 2015. *Journal of Climate*, *31*(6), 2465-2486.

Piya, L., Maharjan, K. L., & Joshi, N. P. (2012). Perceptions and realities of climate change among the Chepang communities in rural mid-hills of Nepal. *Journal of Contemporary India Studies: Space and Society, Hiroshima University*, *2*(5), 35-50.

Porter, J.R., Xie, L., Challinor, A.J., Cochrane, K., Howden, S.M., Iqbal, M.M., Lobell, D.B. and Travasso, M.I. (2014). Food security and food production systems. https://eprints.whiterose.ac.uk/110945/

Pörtner, H. O., Roberts, D. C., Adams, H., Adler, C., Aldunce, P., Ali, E., ... & Ibrahim, Z. Z. .(2022). *Climate change 2022: Impacts, adaptation and vulnerability*. IPCC Sixth Assessment Report. https://www.ipcc.ch/report/sixth-assessment-report-working-group-ii/

Prasanna, V. (2014). Impact of monsoon rainfall on the total foodgrain yield over India. *Journal of earth system science*, *123*(5), 1129-1145.

Praveen, B., & Sharma, P. (2019). A review of literature on climate change and its impacts on agriculture productivity. *Journal of Public Affairs*, *19*(4), e1960.

Ramaano, A. I. (2021). Potential of ecotourism as a mechanism to buoy community livelihoods: the case of Musina Municipality, Limpopo, South Africa. *Journal of Business and Socio-economic Development*, *1*(1), 47-70.

Reidmiller, D. R., Avery, C. W., Easterling, D. R., Kunkel, K. E., Lewis, K. L. M., Maycock, T. K., & Stewart, B. C. (2018). US Global Change Research Program: Washington. *DC, USA*, *2*. https://repository.library.noaa.gov/view/noaa/19487

Reppin, S., Kuyah, S., de Neergaard, A., Oelofse, M., & Rosenstock, T. S. (2020). Contribution of agroforestry to climate change mitigation and livelihoods in Western Kenya. *Agroforestry Systems*, *94*, 203-220.

Ricart, S., Castelletti, A., & Gandolfi, C. (2022). On farmers' perceptions of climate change and its nexus with climate data and adaptive capacity. A comprehensive review. *Environmental Research Letters*. doi10.1088/1748-9326/ac810f.

Ringler, C., Zhu, T., Cai, X., Koo, J., & Wang, D. (2010). *Climate change impacts on food security in Sub-Saharan Africa: Insights from comprehensive climate change scenarios* (No. 1042). International Food Policy Research Institute (IFPRI).

Roco, L., Engler, A., Bravo-Ureta, B., & Jara-Rojas, R. (2014). Farm level adaptation decisions to face climatic change and variability: Evidence from Central Chile. *Environmental Science & Policy*, *44*, 86-96.

Rogers, E. M. (2004). A prospective and retrospective look at the diffusion model. *Journal of health communication*, *9*(S1), 13-19.

Rosenbaum, P. R., & Rosenbaum, P. R. (2002). *Overt bias in observational studies* (pp. 71-104). Springer New York.

Rosenbaum, P. R., & Rubin, D. B. (1983). The central role of the propensity score in observational studies for causal effects. *Biometrika*, *70*(1), 41-55.

Rowell, D. P., Booth, B. B., Nicholson, S. E., & Good, P. (2015). Reconciling past and future rainfall trends over East Africa. *Journal of Climate*, *28*(24), 9768-9788.

Ruben, R., Wattel, C., & Van Asseldonk, M. (2019). Rural finance to support climate change adaptation: Experiences, lessons and policy perspectives. *The Climate-Smart Agriculture Papers, 301*.

Ruben, R., Wattel, C., & Van Asseldonk, M. (2019). Rural finance to support climate change adaptation: Experiences, lessons and policy perspectives. *The Climate-Smart Agriculture Papers*, *301*.

Rutebuka, J., Uwimanzi, A. M., Nkundwakazi, O., Kagabo, D. M., Mbonigaba, J. J. M., Vermeir, P., & Verdoodt, A. (2021). Effectiveness of terracing techniques for controlling soil erosion by water in Rwanda. *Journal of Environmental Management*, *277*, 111369.

Saji, N. H., Goswami, B. N., Vinayachandran, P. N., & Yamagata, T. (1999). A dipole mode in the tropical Indian Ocean. *Nature*, *401*(6751), 360-363.

Sajons, G. B. (2020). Estimating the causal effect of measured endogenous variables: A tutorial on experimentally randomized instrumental variables. *The Leadership Quarterly*, *31*(5), 101348.

Salahuddin, M., Gow, J., & Vink, N. (2020). Effects of environmental quality on agricultural productivity in sub–Saharan African countries: A second generation panel based empirical assessment. *Science of The Total Environment*, *741*, 140520.

Sambrook, K., Konstantinidis, E., Russell, S., & Okan, Y. (2021). The role of personal experience and prior beliefs in shaping climate change perceptions: a narrative review. *Frontiers in psychology*, *12*, 669911.

Sambrook, K., Konstantinidis, E., Russell, S., & Okan, Y. (2021). The role of personal experience and prior beliefs in shaping climate change perceptions: a narrative review. *Frontiers in psychology*, *12*, 669911.

Sani, S., & Kemaw, B. (2019). Analysis of households food insecurity and its coping mechanisms in Western Ethiopia. *Agricultural and food economics*, *7*(1), 1-20.

Sardar, A., Kiani, A. K., & Kuslu, Y. (2021). Does adoption of climate-smart agriculture (CSA) practices improve farmers' crop income? Assessing the determinants and its impacts in Punjab province, Pakistan. *Environment, Development and Sustainability*, *23*, 10119-10140.

Sardar, A., Kiani, A. K., & Kuslu, Y. (2021). Does adoption of climate-smart agriculture (CSA) practices improve farmers' crop income? Assessing the determinants and its impacts in Punjab province, Pakistan. *Environment, Development and Sustainability*, *23*, 10119-10140.

Sedebo, D. A., Li, G., Etea, B. G., Abebe, K. A., Ahiakpa, J. K., Arega, Y., & Anran, Z. (2022). Impact of smallholder farmers' climate-smart adaptation practices on wheat yield in southern Ethiopia. *Climate and Development*, *14*(3), 282-296.

Seife, T. K. (2021). The impact of climate change on agriculture and food security in the greater horn of Africa. *Politikon*, *48*(1), 98-114.

Seleshi, Y., & Zanke, U. (2004). Recent changes in rainfall and rainy days in Ethiopia. *International Journal of Climatology*, *24*(8), 973-983.

Sen, P. K. (1968). Estimates of the regression coefficient based on Kendall's tau. *Journal of the American statistical association*, *63*(324), 1379-1389.

Senyolo, M. P., Long, T. B., Blok, V., & Omta, O. (2018). How the characteristics of innovations impact their adoption: An exploration of climate-smart agricultural innovations in South Africa. *Journal of Cleaner Production*, *172*, 3825-3840.

Sertse, S. F., Khan, N. A., Shah, A. A., Liu, Y., & Naqvi, S. A. A. (2021). Farm households' perceptions and adaptation strategies to climate change risks and their determinants: Evidence from Raya Azebo district, Ethiopia. *International Journal of Disaster Risk Reduction*, *60*, 102255.

Shawul, A. A., & Chakma, S. (2020). Trend of extreme precipitation indices and analysis of long-term climate variability in the Upper Awash basin, Ethiopia. *Theoretical and Applied Climatology*, *140*(1-2), 635-652.

Shukla, R., Gleixner, S., Yalew, A. W., Schauberger, B., Sietz, D., & Gornott, C. (2021). Dynamic vulnerability of smallholder agricultural systems in the face of climate change for Ethiopia. *Environmental Research Letters*, *16*(4), 044007.

Sida, T. S., Baudron, F., Kim, H., & Giller, K. E. (2018). Climate-smart agroforestry: Faidherbia albida trees buffer wheat against climatic extremes in the Central Rift Valley of Ethiopia. *Agricultural and forest meteorology*, *248*, 339-347.

Silvestri, S., Bryan, E., Ringler, C., Herrero, M., & Okoba, B. (2012). Climate change perception and adaptation of agro-pastoral communities in Kenya. *Regional Environmental Change*, *12*, 791-802.

Singh, A. S., Zwickle, A., Bruskotter, J. T., & Wilson, R. (2017). The perceived psychological distance of climate change impacts and its influence on support for adaptation policy. *Environmental Science & Policy*, *73*, 93-99.

Singh, D., Tsiang, M., Rajaratnam, B., & Diffenbaugh, N. S. (2013). Precipitation extremes over the continental United States in a transient, high-resolution, ensemble climate model experiment. *Journal of Geophysical Research: Atmospheres*, *118*(13), 7063-7086.

Singh, R., Worku, M., Bogale, S., Cullis, A., Adem, A., Irwin, B., Lim, S., Bosi, L. and Venton, C.C. (2016). Reality of resilience: Perspectives of the 2015-16 drought in Ethiopia. *BRACED Resilience Intel*, *6*, 1-28.

Smith, J. A., & Todd, P. E. (2005). Does matching overcome LaLonde's critique of nonexperimental estimators?. *Journal of econometrics*, *125*(1-2), 305-353.

Solomon, N., Birhane, E., Gordon, C., Haile, M., Taheri, F., Azadi, H., & Scheffran, J. (2018). Environmental impacts and causes of conflict in the Horn of Africa: A review. *Earth-science reviews*, *177*, 284-290.

Solomon, R., Simane, B., & Zaitchik, B. F. (2021). The impact of climate change on agriculture production in Ethiopia: application of a dynamic computable general equilibrium model. *American Journal of Climate Change*, *10*(1), 32-50.

Stuch, B., Alcamo, J., & Schaldach, R. (2021). Projected climate change impacts on mean and year-to-year variability of yield of key smallholder crops in Sub-Saharan Africa. *Climate and Development*, *13*(3), 268-282.

Suckall, N., Fraser, E., & Forster, P. (2017). Reduced migration under climate change: Evidence from Malawi using an aspirations and capabilities framework. *Climate and Development*, *9*(4), 298-312.

Svoboda, M., Hayes, M., & Wood, D. (2012). Standardized precipitation index user guide. *World Meteorological Organization*, *1090*.

Tadesse, M., Kebede, M., & Girma, D. (2021). Genetic diversity of tef [eragrostis tef (zucc.) trotter] as revealed by microsatellite markers. *International journal of genomics*, *2021*.

Tafesse, A., Goshu, D., Gelaw, F., & Ademe, A. (2020). Food and nutrition security impacts of Moringa: Evidence from Southern Ethiopia. *Cogent Food & Agriculture*, *6*(1), 1733330.

Talanow, K., Topp, E. N., Loos, J., & Martín-López, B. (2021). Farmers' perceptions of climate change and adaptation strategies in South Africa's Western Cape. *Journal of Rural Studies*, *81*, 203-219.

Taye, M., Yilma, M., Mengistu, S., Abiso, T., Bassa, Z., Wolde, S., Rischkowsky, B., Dessie, T., Okeyo, M. and Haile, A. (2016). Characterization of production system and breeding practices of sheep producers in Doyogena district, Southern Ethiopia. *African Journal of Agricultural Research*, *11*(52), 5192-5201.

Taylor, M. (2018). Climate-smart agriculture: what is it good for?. *The Journal of Peasant Studies*, *45*(1), 89-107.

Tegegne, G., & Melesse, A. M. (2021). Comparison of trend preserving statistical downscaling algorithms toward an improved precipitation extremes projection in the headwaters of blue nile river in Ethiopia. *Environmental Processes*, *8*, 59-75.

Teka, A., & Lee, S. K. (2020). Do agricultural package programs improve the welfare of rural people? Evidence from smallholder farmers in Ethiopia. *Agriculture*, *10*(5), 190.

Teketel, M., Temesgen, D., Hamza, D., & Fesseha, H. (2021). Determinants of smallholder farmers' participation in improved sheep production: The case of Doyogena District, Kembata Tembaro Zone, Southern Ethiopia. *Advances in Agriculture*, *2021*, 1-17.

Teklewold, H., Mekonnen, A., & Kohlin, G. (2019). Climate change adaptation: A study of multiple climate-smart practices in the Nile Basin of Ethiopia. *Climate and Development*, *11*(2), 180-192.

Teklu, A., Simane, B., & Bezabih, M. (2022). Effectiveness of Climate-Smart Agriculture Innovations in Smallholder Agriculture System in Ethiopia. *Sustainability*, *14*(23), 16143.

Tendall, D.M., Joerin, J., Kopainsky, B., Edwards, P., Shreck, A., Le, Q.B., Krütli, P., Grant, M. and Six, J. (2015). Food system resilience: Defining the concept. *Global Food Security*, *6*, 17-23.

Tesfahunegn, G. B., & Gebru, T. A. (2021). Climate change effects on agricultural production: insights for adaptation strategy from the context of smallholder farmers in Dura catchment, northern Ethiopia. *GeoJournal*, *86*(1), 417-430.

Tesfay, M. G. (2020). Does fertilizer adoption enhance smallholders' commercialization? An endogenous switching regression model from northern Ethiopia. *Agriculture & Food Security*, *9*(1), 1-18.

Tesfaye, S., Bedada, B., & Mesay, Y. (2016). Impact of improved wheat technology adoption on productivity and income in Ethiopia. *African Crop Science Journal*, *24*(s1), 127-135.

Teshome, H., Tesfaye, K., Dechassa, N., Tana, T., & Huber, M. (2021). Smallholder farmers' perceptions of climate change and adaptation practices for maize production in Eastern Ethiopia. *Sustainability*, *13*(17), 9622.

Tessema, I., & Simane, B. (2021). Smallholder Farmers' perception and adaptation to climate variability and change in Fincha sub-basin of the Upper Blue Nile River Basin of Ethiopia. *GeoJournal*, *86*(4), 1767-1783.

Thinda, K. T., Ogundeji, A. A., Belle, J. A., & Ojo, T. O. (2021). Determinants of relevant constraints inhibiting farmers' adoption of climate change adaptation strategies in South Africa. *Journal of Asian and African Studies*, *56*(3), 610-627.

Thornton, P. K., & Herrero, M. (2015). Adapting to climate change in the mixed crop and livestock farming systems in sub-Saharan Africa. *Nature Climate Change*, *5*(9), 830-836.

Tierney, J. E., Smerdon, J. E., Anchukaitis, K. J., & Seager, R. (2013). Multidecadal variability in East African hydroclimate controlled by the Indian Ocean. *Nature*, *493*(7432), 389-392.

Tigabu, D. G., & Gebeyehu, M. F. (2018). *Agricultural extension service and technology adoption for food and nutrition security: Evidence from Ethiopia*. FARA Research Report 3 (4): 30.

Tofu, D. A., Woldeamanuel, T., & Haile, F. (2022). Smallholder farmers' vulnerability and adaptation to climate change induced shocks: The case of Northern Ethiopia highlands. *Journal of Agriculture and Food Research*, *8*, 100312.

Tong, S., & Ebi, K. (2019). Preventing and mitigating health risks of climate change. *Environmental research*, *174*, 9-13.

Tsegaye, W., LaRovere, R., Mwabu, G., & Kassie, G. T. (2017). Adoption and farm-level impact of conservation agriculture in Central Ethiopia. *Environment, Development and Sustainability*, *19*, 2517-2533.

Tsige, M., Synnevåg, G., & Aune, J. B. (2020). Gendered constraints for adopting climate-smart agriculture amongst smallholder Ethiopian women farmers. *Scientific African*, *7*, e00250.

Uddin, M. N., Bokelmann, W., & Dunn, E. S. (2017). Determinants of farmers' perception of climate change: a case study from the coastal region of Bangladesh. *American Journal of Climate Change*, *6*(1), 151-165.

Ullah, A., Arshad, M., Kächele, H., Khan, A., Mahmood, N., & Müller, K. (2020). Information asymmetry, input markets, adoption of innovations and agricultural land use in Khyber Pakhtunkhwa, Pakistan. *Land use policy*, *90*, 104261.

Union, A. (2015). Agenda2063 report of the commission on the African Union Agenda 2063 The Africa we want in 2063.

Urgessa, G. K. (2013). Spatial and temporal uncertainty of rainfall in arid and semi-arid areas of Ethiopia. *Science, Technology and Arts Research Journal*, *2*(4), 106-113.

Van de Ven, W. P., & Van Praag, B. M. (1981). The demand for deductibles in private health insurance: A probit model with sample selection. *Journal of econometrics*, *17*(2), 229-252.

van Weezel, S. (2019). On climate and conflict: Precipitation decline and communal conflict in Ethiopia and Kenya. *Journal of Peace Research*, *56*(4), 514-528.

Viste, E., Korecha, D., & Sorteberg, A. (2013). Recent drought and precipitation tendencies in Ethiopia. *Theoretical and Applied Climatology*, *112*, 535-551.

von Braun, J. (2020). Climate change risks for agriculture, health, and nutrition. *Health of People, Health of Planet and Our Responsibility: Climate Change, Air Pollution and Health*, 135-148.

von Braun, J., & Birner, R. (2017). Designing global governance for agricultural development and food and nutrition security. *Review of Development Economics*, *21*(2), 265-284.

Waaswa, A., Oywaya Nkurumwa, A., Mwangi Kibe, A., & Ngeno Kipkemoi, J. (2022). Climate-Smart agriculture and potato production in Kenya: review of the determinants of practice. *Climate and Development*, *14*(1), 75-90.

Wagesho, N., Goel, N. K., & Jain, M. K. (2013). Temporal and spatial variability of annual and seasonal rainfall over Ethiopia. *Hydrological Sciences Journal*, *58*(2), 354-373.

Wainaina, P., Tongruksawattana, S., & Qaim, M. (2016). Tradeoffs and complementarities in the adoption of improved seeds, fertilizer, and natural resource management technologies in Kenya. *Agricultural Economics*, *47*(3), 351-362.

Wake, R. D., & Habteyesus, D. G. (2019). Impact of high yielding wheat varieties adoption on farm income of smallholder farmers in Ethiopia. *International Journal of Agricultural Extension*, *7*(1), 45-59.

Walker, S. E., Bruyere, B. L., Zarestky, J., Yasin, A., Lenaiyasa, E., Lolemu, A., & Pickering, T. (2022). Education and adaptive capacity: The influence of formal education on climate change adaptation of pastoral women. *Climate and Development*, *14*(5), 409-418.

Warinda, E., M. Nyariki, D., Wambua, S., & Muasya, R. (2020). Impact of smallholder farmers' welfare through participation in on-farm regional projects in East Africa. *Agrekon*, *59*(1), 16-29.

Warinda, E., Nyariki, D. M., Wambua, S., Muasya, R. M., & Hanjra, M. A. (2020, February). Sustainable development in East Africa: impact evaluation of regional agricultural development projects in Burundi, Kenya, Rwanda, Tanzania, and Uganda. In *Natural Resources Forum* (Vol. 44, No. 1, pp. 3-39). Oxford, UK: Blackwell Publishing Ltd.

Wassie, A. S., & Pauline, N. M. (2020). Effectiveness of existing climate smart agricultural practices in Tehuledere district, north-eastern Ethiopia. In *Climate change impacts and sustainability: ecosystems of Tanzania* (pp. 180-193). Wallingford UK: CABI.

Wayessa, G. O. (2021). State-Building and Development in Ethiopia: From “Developmental State” to “Prosperity” Model. *Northeast African Studies*, *21*(2), 83-115.

Wekesa, B. M., Ayuya, O. I., & Lagat, J. K. (2018). Effect of climate-smart agricultural practices on household food security in smallholder production systems: micro-level evidence from Kenya. *Agriculture & Food Security*, *7*(1), 1-14.

Weldearegay, S. K., & Tedla, D. G. (2018). Impact of climate variability on household food availability in Tigray, Ethiopia. *Agriculture & Food Security*, *7*, 1-9.

Weldegebriel, Z. B., & Prowse, M. (2017). Climate variability and livelihood diversification in northern Ethiopia: a case study of Lasta and Beyeda districts. *The Geographical Journal*, *183*(1), 84-96.

Wens, M. L., Mwangi, M. N., van Loon, A. F., & Aerts, J. C. (2021). Complexities of drought adaptive behaviour: Linking theory to data on smallholder farmer adaptation decisions. *International Journal of Disaster Risk Reduction, 63*, 102435.

WFP, V. A. M. (2008). Food consumption analysis: calculation and use of the food consumption score in food security analysis. *WFP: Rome, Italy*.

Wheeler, S., Zuo, A., & Bjornlund, H. (2013). Farmers’ climate change beliefs and adaptation strategies for a water scarce future in Australia. *Global Environmental Change*, *23*(2), 537-547.

Wodaje, G. G., Eshetu, Z., & Argaw, M. (2016). Temporal and spatial variability of rainfall distribution and evapotranspiration across altitudinal gradient in the Bilate River Watershed, Southern Ethiopia. *African Journal of Environmental Science and Technology*, *10*(6), 167-180.

Wooldridge, J. M. (2010). *Econometric analysis of cross section and panel data*. MIT press.

Wooldridge, J. M. (2016). Should instrumental variables be used as matching variables?. *Research in Economics*, *70*(2), 232-237.

Wordofa, M. G., Hassen, J. Y., Endris, G. S., Aweke, C. S., Moges, D. K., & Rorisa, D. T. (2021). Adoption of improved agricultural technology and its impact on household income: a propensity score matching estimation in eastern Ethiopia. *Agriculture & Food Security*, *10*, 1-12.

World Bank Group, & Asian Development Bank. (2021). *Climate Risk Country Profile*: Kyrgyz Republic. World Bank. Washington DC.

World Bank. (2021). *Climate Risk Country Profile: Ethiopia*. The World Bank Group, World Bank. Washington DC.

World Food Program (WFP). (2014). *Climate risk and food security in Ethiopia*: *Analysis of climate impacts on food security and livelihoods*. Retrieved from https://documents.wfp.org/stellent/groups/public/documents/newsroom/wfp269379.pdf.

Wossen, T., Abdoulaye, T., Alene, A., Feleke, S., Menkir, A., & Manyong, V. (2017). Measuring the impacts of adaptation strategies to drought stress: The case of drought tolerant maize varieties. *Journal of Environmental Management*, *203*, 106-113.

Wouterse, F., Andrijevic, M., & Schaeffer, M. (2022). The microeconomics of adaptation: Evidence from smallholders in Ethiopia and Niger. *World Development*, *154*, 105884.

Wuepper, D., Yesigat Ayenew, H., & Sauer, J. (2018). Social capital, income diversification and climate change adaptation: Panel data evidence from rural Ethiopia. *Journal of agricultural economics*, *69*(2), 458-475.

Yamane, T. (1967). *An Introductory statistics analysis*, 2nd Ed., harper, New York., 919 pp

Yu, B., & Nin-Pratt, A. (2014). Fertilizer adoption in Ethiopia cereal production. *Journal of Development and Agricultural Economics*, *6*(7), 318-337.

Zakari, S., Ibro, G., Moussa, B., & Abdoulaye, T. (2022). Adaptation strategies to climate change and impacts on household income and food security: Evidence from Sahelian region of Niger. *Sustainability*, *14*(5), 2847.

Zerssa, G., Feyssa, D., Kim, D. G., & Eichler-Löbermann, B. (2021). Challenges of smallholder farming in Ethiopia and opportunities by adopting climate-smart agriculture. *Agriculture*, *11*(3), 192.

Zewdu, E., Hadgu, G., & Nigatu, L. (2020). Impacts of climate change on sorghum production in North Eastern Ethiopia. *African Journal of Environmental Science and Technology*, *14*(2), 49-63.

Zougmoré, R. B., Läderach, P., & Campbell, B. M. (2021). Transforming food systems in Africa under climate change pressure: Role of climate-smart agriculture. *Sustainability*, *13*(8), 4305.

Appendixes

Appendix 'A' Distribution of sampled households by Villages Are these results

Kebeles	Villages	Total Households	Sampled households	Male household heads	Female household heads
Lemisuticho	Tula	1733	65	48	16
	Suticho	2428	91	78	14
	Cherema	1360	51	41	10
	Kanko	853	32	27	5
Begedamo	Gateme	1707	64	48	16
	Bakucho	1013	38	33	5
	Tach- begedamo	880	33	27	6
	Lay- begedamo	293	11	8	3
Total households		**10267**	**385**	**310(80.5%)**	**75(19.5%)**

Source: Author's own construction from fieldwork 2020/2021

Appendix 'B' Profile of Focus group discussion participants (F-Female; M-male)

Attributes	Lemisuticho	Begedamo
Age	50-60	40-60
Education	1-12 grade	1-12 grade
Farming experience	>30 years	>30 years
Number of participants from the farmers	10(6 M,4 F)	10(6 M,4 F)
Development agents	1	1
Kebele administration	1	1
Sub-total	12	12
Total		**24**

Source: Author's own construction from fieldwork 2020/2021

Appendix 'C' Profile of Key informants' participants (F-Female; M-male)

Attributes	Lemisuticho	Begedamo
Age	40-60	40-60
Education	6-12 grade	1-12 grade
Farming experience	>30 years	>30 years
Number of participants from the farmers	4(3 M,1 F)	4(3 M,1 F)
Development agents	1	1
Kebele administration	1	1
NGOs	1	1
Community leader (Idir)	1	1
Sub-total	8	8
Total		**16**

Source: Author's own construction from fieldwork 2020/2021

Appendix 'D' List of CSA practices as adaptation strategies

List of CSA practices as an adaptation strategy	**Farmers response Yes ('1') No ('0')**
Framers practicing soil and water conservation with biological measures	
Farmers using improved crop varieties (wheat, potato, beans, seeds)	
Farmers using crop rotation	
Farmers adopting Agroforestry (woody perennials and fruit crops; fallow)	
Farmers using improved breeds (sheep and cattle)	
Farmers using controlled grazing	
Farmers using residue incorporation for Wheat or Barley	
Farmers using green manure	
Farmers using cut and carry system	
Farmers using minimum tillage/mulching	

Source: field work 2020/2021

Appendix 'E' Variables summaries used in the model.

Variable	Explanation	Mean	Std. Dev.
CSA Adoptions	1 for adopters; 0 otherwise	0.618	0.486
Climate change perceptions	1 for perceived; 0 otherwise	0.868	0.339
Age	The actual age of the household head in years	50.423	13.461
Education	Level of education in years	3.112	3.854
Family size	The number of family members in the household	7.429	2.451
Gender	1 for male, 0 otherwise	0.805	0.397
Landholding size	Total crop landholding in hectares	0.617	0.466
Farming experiences	The actual farming experience of the household	25.67	13.538
Distance outputmar~t	The distance of input and output market in km	4.871	5.7
Access climatetinf~n	1 for access to climate information; 0 otherwise	0.771	0.42
Contact extension	The number of annual contact with extension agents	5.117	12.298
Training received	1 if the farmers had received training; 0 otherwise	0.732	0.443
Access credit	1 if the farmers had access to credit; 0 otherwise	0.286	0.452
Social membership	1 if the farmer was a member of a social group; 0	0.956	0.206
TLU	The tropical livestock unit	2.442	1.868
Income	Estimated annual income in Ethiopian currency	12571.66	907.48
Soil fertility	1 if a farmer has fertile soil; 0 otherwise	0.63	0.04
Rainfall	average annual rainfall in millimeter(mm)	1249.1	441.336
Slop of farm plot	1 if farm plot is steep slop; 0 otherwise	0.56	0.032

Appendix 'F'

Farmers were asked what types of foods they had consumed over the last seven days (one week) among which includes cereals (maize, teff, wheat, sorghum, millet); tubers (potatoes, sweet potatoes), pulses and nuts (beans, lentils, peas, peanuts, and so on); vegetables and fruits; meat and fish (beef, goat, poultry, pork, eggs, and fish); dairy products (milk, yoghurt, cheese, and other milk products); sugar and honey; oil, fat, and butter and computed based on the table below.

Food categories	Food groups(definitive)	Weight (definitive)
Maize, maize porridge, rice, sorghum, millet pasta, bread, and other cereals	Main staples	2
Cassava, potatoes and sweet potatoes, other tubers, plantains		
Beans. Peas, groundnuts, and cashew nuts	Pules	3
Vegetables, leaves	Vegetables	1
Fruits	fruit	4
Beef, goat, poultry, pork, eggs, and fish	Meat and fish	4
Milk yogurt and other diary	Milk	4
Sugar and sugar products, honey	Sugar	0.5
Oils, fats, and butter	Oil	0.5
spices, tea, coffee, salt, fish power, small amounts of milk for tea.	Condiments	0

Annex 'G'

Table : Rosenbaum bounds for **_FCS** (N = 384 matched pairs)

Gamma	sig+	sig-	t-hat+	t-hat-	CI+	CI-
1	0	0	39.9876	39.9876	39.9876	39.9876
1.25	0	0	39.9876	39.9876	39.9876	39.9876
1.5	0	0	39.9876	39.9876	39.9876	43.7264
1.75	0	0	39.9876	39.9876	39.9876	43.7264
2	0	0	39.9876	43.7264	39.9876	43.7264

* gamma - log odds of differential assignment due to unobserved factors

sig+ - upper bound significance level

sig- - lower bound significance level

t-hat+ - upper bound Hodges-Lehmann point estimate

t-hat- - lower bound Hodges-Lehmann point estimate

CI+ - upper bound confidence interval (a = .95)

CI- - lower bound confidence interval (a = .95)

Table ?: Rosenbaum bounds for **log crop income** (N = 384 matched pairs)

Gamma	sig+	sig-	t-hat+	t-hat-	CI+	CI-
1	0	0	10500	10500	9500	11450
1.25	0	0	9500	11400	8700	12500
1.5	0	0	8850	12250	8000	13500
1.75	0	0	8325	13000	7500	14500
2	0	0	7900	13750	7100	15500

* gamma - log odds of differential assignment due to unobserved factors

sig+ - upper bound significance level

sig- - lower bound significance level

t-hat+ - upper bound Hodges-Lehmann point estimate

t-hat- - lower bound Hodges-Lehmann point estimate

CI+ - upper bound confidence interval (a = .95)

CI- - lower bound confidence interval (a = .95)

Appendix 'H': Glossary of Terms

Adaptation: Adaptation is defined "it is adjustment in ecological, social, or economic systems in response to actual or expected climatic stimulus and their effects or impacts" (IPCC, 2014: 76).

Climate change: Climate change is defined by the IPCC as "a change in the state of the climate that can be determined (e.g., using statistical tests) by changes in the mean and/or variability of its attributes and that persists for an extended period, typically three decades or longer" (IPCC, 2014:120)

Climate Smart Agriculture (CSA): " is an integrated approach that sustainably increases agriculture productivity, enhances resilience (adaptation), reduces/removes GHGs (mitigation) where possible, and enhances achievement of national food security and development goals" (FAO,2010)

Climate variability: Climate variability "refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all spatial and temporal scales beyond that of individual weather events" (IPCC, 2014:121).

Food Consumption Score: "The variety and frequency of food groups consumed during the previous week, which is then weighted according to the relative nutritional value of the consumed food groups" (WFP, 2008).

Food security: "situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" FAO (2002).

Knowledge: It is defined as the main component for a basic understanding of an issue and reasoning in decision making about the issue (Jho and Kim, 2014).

Perception: "It is the process by which we receive information or stimuli from our environment and transform it into psychological awareness" (IPCC, 2014)

Resilience: Resilience is defined as " the ability of a system's (social, economic, and environmental) to cope with and recover from the effects of a hazardous event or disturbance" (IPCC, 2014).

Appendix 'I': Questionnaire

Climate Smart Agriculture Practices by smallholder Farmers under Changing Climate in the Southern Ethiopia

Survey Questionnaire

Prepared by Abrham Belay

General Instructions to Enumerators

- Make brief introduction before starting any question, introduce yourself to the respondents, greet them in local ways and make clear the purpose and objective of the study.
- Please fill the interview schedule according to the farmers reply (please do not put your own opinion).
- Please ask each question clearly and patiently until the respondents gets your points.
- Please do not use technical terms and do not forget local units.
- During the process, put the answer of each respected respondent both on the space provided and CIRCLE on the choice.

Household Identification

<table>
<tr><td>[Date/Month /Year]

________________</td><td colspan="2">1. Enumerator's Name:
_______________________</td><td>2. Questionnaire Code:
_______________</td></tr>
<tr><td colspan="2">3. District/Woreda__________________</td><td colspan="2">4. Kebele_________ 5 Village____________</td></tr>
<tr><td colspan="4">6. Name of respondent_______________________7. Name of field supervisor_______________

8. Easting: ________________9. Northing ___________________ 10. Altitude __________</td></tr>
</table>

11. Economic status of the household: 1=Poor, 2 = Medium, 3 = Better-off/rich

A. Household characteristics

1. Total family size of the household? ___________Male____ Female____
2. Gender of the household's head 1= male 0= female,
3. Age of the household's head in years _______
4. Educational status of the household's head? Can read and write? 1= Yes 0= No, if no (skip to Q.5)
5. If your answer is yes for Q4, give the highest level of education in years (________), 1 =primary 2= secondary 3= tertiary
6. Marital status of the household's head? 1=Single 2= Married 3=Widowed=4. Divorced/Separated
7. Types of house you have፡ 1= straw/Grass house 2= Corrugated iron house 3= both
8. What is your major occupation 1= Farmer 2=Trader 3= daily laborer 4= Civil Servant
9. 5= Unemployed 6=both farmer and trader
10. Total land holding size in hectare___________
11. How did you acquire land for farming?
    1 = First distribution 2= Inherited 3= sharecropping 4 = Renting in 5=Gift
12. Average distance of your farm plots from your home in minute_____ in km________
13. Average distance of the school from your home in minute_____ km________
14. Average distance of the farmer training center from your home in minute_____ km________
15. Farming experience in years___________
16. Total annual income in ETB (refer section E) ___________ (Farm crops selling________ Livestock selling_________wood/plantation selling________ other off farm income sources________
17. How do you estimate your level of level expenditure? Food conception_____, clothing____, and farm inputs _________other utilities__________
18. Do you have access to extension services 1=yes 0=No?
19. If Yes, distance of extension office in km from your home in minute_____ km________

20. Do you have access to input market? 1=Yes=No
21. If Yes, average distance in km from your home in minute_____ km________
22. Do you have access to output market? 1=yes 0=No
23. If yes, average distance from your home in km _______

B: **Perception on climate change and variability**

24. Do you know about climate change? 1= yes 0= No
25. How do you perceive temperature change for the last 30 years?
    Don't Know 2= No change 3= Decrease 4= Increase
26. How do you perceive rainfall change for the last 30 years?
    1= Don't Know 2= No change 3= Decrease 4= Increase
27. Has the number of hot days over the last 30 years 1= Increased 2= Decreased?
    3= Stayed the same 4= Don‘t know
28. Has the number of rainfall days over the last 30 years? 1= Increased 2= Decreased 3= Stayed the same 4= Don‘t knows
29. What was the recent amount of precipitation during a rainy season in contrast to the last 10-30 years?
    1= Very low 2 =Low 3= Normal 4= High 5=Very high
30. What were the main changes you have observed regarding rains and temperature?

    30.1 Changes of rain starting time? 1= Earlier 2= later 3=no change
    30.2 Change of rainfall intensity? 1= lighter 2=heavier 3=no change
    30.3 Changes of rain ending time? 1=Shorter2= longer3= no change
    30.4 Change of temperature? 1=warmer 2=cooler 3= no change

31. Have you encountered drought over the last 30 years? 1= Yes 2= No 3= Don‘t know
32. If yes, how do you describe the frequency of occurrence of drought for the last 5-10 years in years as compared to the past 30 years? 1= Increased 2= Decreased 3= Followed a similar trend
33. Have you encountered a flooding problem over the last 30 years? 1= Yes 2= No 3= Don‘t know
34. If yes, how do you describe the frequency of occurrence of flood in last 5-10 years as compared to the past 30 years? 1= Increased 2= Decreased 3= Followed a similar trend

35. Have you encountered a pest and disease problem over the last 30 years? 1= Yes 2= No 3= Don‘t know
36. If yes, how do you describe the frequency of occurrence of pest and disease in recent years as compared to the past 30 years? 1= Increased 2= Decreased 3= Followed a similar trend
37. Since when you have noticed that the overall climate condition of your area has changed?
38. 1=10 years 2=20 years 3= 30 years 4=40 years
39. Did you have access to climate information? 1= Yes 0= No
40. If your answer for Q39 is yes through which channel did you receive the climate information?
41. 1= Radio 2= Mobile phone 3=Personal contact or social group 4= Research institutions/NGOs 5= Development agents 5= another channel, specify __________
42. Did you understand the content of the information you received? 1= Yes, 0= No.
43. Did you get the information on time (e.g. before/during the planting season)? 1= Yes, 0= No.
44. Did you personally have access to seasonal forecast for expected rains for the next month's 1=yes 0= no,
45. If your answer for q 44 is yes, in response to the seasonal forecast did you undertake changes in your crop and livestock activities? 1= Yes 0=No
46. Did you receive any training on seasonal weather forecast? 1= Yes 0= No
47. If your answer for q42 is yes, who has provided the training? 1=I don't remember 2=Government agricultural extension 3=Metrological office 4= No government institutions 5= Other____

C. Climate related hazards/risks on farmers' livelihood systems

48. Do you know about climate change related risks/hazard? 1=Yes 0=No
49. If yes for the above question 48, what is your level of perception/understating on climate change related risks/hazard? 1= highly perceived 2= moderately perceived 3= less perceived 4= Not sure
50. Did you have access to early warning on climate change and variability 1=Yes 0=No

	Climate change risk perception	Predicted/expected climate related risks/hazards in the future	Degree of risk perception
			4 = high; 3 = moderate; 2 = low; 1= not sure
1	Climatic variables	Probability of droughts, floods and dry spell	
		Probability of increased temperature and decrease rainfall	
2	Health and socio-economic	Severity of consequences on human diseases and mortality	
		Severity consequences on food security and incomes	
		Severity of consequences on migration	
	Biodiversity and forestry	Probability of reduction in plant and forest species and decrease forest area	
		Probability of reduction in animal species	
4	Agricultural production	Probability of decrease crop yield	
		Probability of increase in pests and diseases	
		Probability of increase in cost of production	
		Probability of decrease in soil fertility	
5	Psychological	Perceived ability to control risk	

51. Did any climate relate risks affected the household production or income in the previous years?

1=Yes 0= No

N0.	52. If yes for Q51, which major climate-related hazards/risks have affected the household during the last 20-30 years?	Degree of exposure/ impact 0=no impact, 1= low impact, 2= medium impact

	(**You can choose more than one and rank them by degree impact in priority order** Type of climate-related hazards	3= high impact
1	Drought	
2	Flooding	
3	Shortage of rain	
4	Increased temperature	
5	Change in rainfall distribution pattern	
6	Animal disease outbreak	
7	Crop pest outbreak	
8	Hunger/Famine	
9	Soil erosion	
10	Human disease outbreak	
11	Land slide/degradation	
12	Storms/strong winds	
13	Frost	
14	Forest fire	
15	Other specify	

53. What was the impact of the climate related hazards on your livelihoods and natural resources?

(**You can choose multiple options**)

N0.	Type of climate-related impacts	**Choose multiple options (√)**
1	Decline in crop yield	
2	Loss of income	
3	Decline in household consumption	
4	Food shortage, food insecurity	
5	Death of livestock and human mortality	
6	Reduced productivity of agricultural land	
7	Reduced water availability and quality	
8	Increase cost of farm inputs	
9	Increase cost of health care	
10	Reduction in soil fertility	

54. Because of the impact of climate shock, did you have to: 1= Shift from on-farm to off-farm work 2=Go elsewhere to get work 3= Saving money 4=borrowed money
55. Because of the negative weather impacts, did you undertake changes in your animal and crop related activities? 1= Did not do any change 2= Changes done but not because of climate 3= Yes, changes done because of climate 4=Integrate crop with livestock
56. Which type of changes you made regarding animal activities 1=Introducing more animal types (diversification) 2. Substitute animals by other animal 3=Change in breed types (substitution) 4. Selling, relocation or migrating herd/stock 5=Changing pasture/ feed management 5= Changing animal number/size 6= Other
57. Which type of changes you made regarding crops/trees activities

1=Introducing new crops 2= did not introduce new crops 3= Yes, but we have had them before 4=Yes, they were totally new 5=we never had them before

D. Risk perception and management strategies (Likert-type scales)

No	58. Do you agree to taking the following risks? **Sources of the risks**	Relative risk aversion. Please give the following scales 1 = strongly disagree 2 = disagree 3 = neutral 4 = agree 5 = strongly agree.				
		1	2	3	4	*5*
1	**Production risk;** (poor performance of production due to climate related risks					
2	**Market risks**; Higher prices of farm inputs, inaccessible market, shortage of inputs in the market					
3	**Institutional risk;** Possible loss of tenure rights, government policies on subsidies of farm inputs *lack of input supply*, *lack of extension services*					
4	**Technological risks;** Adoption of new farm techniques and inputs, expensive adoption cost					
5	**Climate risks**; flooding, drought, loss of soil fertility, disease and pest occurrence					

E. Farming system and farmland /characteristics

59. Total area of cultivated plots/land in hectare______

60. Soil fertility status of your plots 1=good 0= poor

61. Your farm plot soil depth 1= Deep 0= Shallow

62. How the slop of your farm plot is ?1= Gentle slope 0= Steep slop

63. Severity of soil erosion 1=severe 2=moderate 3=low

64. Number of annual contacts with extension workers (put in number) ________

65. Main source of income? 1=Sale of crop 2=sale of animal 3=Sale of trees 4= other

66. Source of water? 1=Traditional well2= Protected spring 3=Unprotected spring 4=Ponds

67. Did you grow crops in your farm last year? 1=Yes 0=No

68. Which crop types did you grow last year? **Choose multiple answers from below table?**

No	Crop types Gown in your farm plot	**Tick√**	Improved	Not improved	Both	Cultivated lands in hectare	Annual Production Kuntal/ha	Consumption in kuntal	Quantity sold (kuntal)	Current stock (kuntal
1	Wheat									
2	Barley									
3	Legumes (Beans, peans)									
4	Enset/false banana									
5	Potato									
6	Carrot									
7	Beetroot									
8	Cabbage									
9	Fruits									

69. Did you raise home animals on your farm? 1=Yes 0=No

70. Which types of animals are raised on the farm? Please use the following table

	Types of animals	**Tick** √	Record their number	Annual income from livestock selling (Birr)	Conversion factor for each animal type	TLU
1	Cattle				1.00	
2	Sheep				0.13	
3	Goat				0.13	
4	Donkey				0.35	
5	Horse				1.1	
6	Chicken/poultry				0.013	

71. Did you grow trees in your farm 1= Yes 0= No

72. Which types of trees you grown in your farm? Please use the following table

	Types of tress/fruits	**Tick** √	Number of trees/hectares	Total annual income from tree/fruit selling in (Birr)
1	Eucalypts(ባህርዛፍ)			
2	Korch (Erytrnia Abyssinia)ኮርች			
3	Bamboo ቀርቀሃ			
4	Fruit trees የፍራፍሬ ዛፍ			
6	Coffee ቡና			
7	Cordia Africana ዋንዛ			
8	Podocarpus ዝግባ			
9	croton macrostachyus ብሳና			
10	Grevilia ግራቪላያ			
11	Legumes tree (የጥራጥሬ ዛፍ ለመኖ እ ና አፈር ለምነት) (treelucern, sesbania,			
12	Cupressus Lusitania የፈረንጅ ጽድ			

F. Training and credit services

73. Did you receive training on farming system? 1=Yes 0=No
74. From whom did you receive the training?1=Government extension worker 2= NGOs 3=Meteorological services 4= other __________-
75. Do you have access to credit services from government or private finance 1= Yes 0=No?
76. From which source do you get credit facility? 1=government 2=Private 3= Both
77. Are you a member of social groups(association) (squab, edire or religious)? 1=Yes 0=No?

G. Climate Smart Agriculture Practices

78. Do you know about climate smart agriculture practices? 1=Yes 0=No
79. Are you currently implementing any of the CSA options? 1=yes 0= No
80. What was the level of understanding on CSA practices?
    1. I have heard about it but don't know how to implement it.
    2. I have never heard about it
    3. I heard about it but did not do
    4. I have already involved and implementing it
    5. I did it before but stopped it now
81. If you implement it before, how much hectare of your land is covered by CSA practices ______?
82. What was the main motivation or reasons to implement such CSA options in your farm land? (**Choose multiple answer**)
    1. Because of learning or training
    2. New market opportunities
    3. in response to negative climate change impact
    4. to adapt future climate shocks
    5. Time saving
    6. Reduce farm inputs
83. If you didn't implement it before, what was the main reason for not adopting of the CSA practices (**Choose multiple answer**)?
    1. Limited supply of farm inputs and materials
    2. Limited credit and finance
    3. Shortage of labor

4. Poor physical and social infrastructure.

5 lack of CSA-relevant information

6. Lack of knowledge and skill.

7 Poor institutional supports

8. Inappropriate technologies

9. Lack of interest

84. From whom you hear /learn these CSA options

1= from other framers 2=Self-learning 3=Training by development agents 4=NGOs

Which of the following CSA options you have had applied on your farm for the last 3-6 years?

No.	CSA options	Aware of the CSA practice	Aware and Applying the CSA practice	Aware but not applying	Give Ranks
1	Soil and water conservation with biological measures				
2	Controlled grazing				
3	Improved crop varieties (wheat, potato, beans, seeds) high yield, disease resistance *and* early maturing)				
4	Crop rotation				
5	Residue incorporation for Wheat or Barley				
6	Green Manure				
7	Improved breeds (sheep and cattle)				
8	Agroforestry (woody perennials and fruit crops; fallow)				
9	Cut and carry system				
10	Minimum tillage, Mulching				

85. How was the implementation of this CSA option affected your time in your agricultural activities? 1= Spend less time 2= Spend more time 3=Spend the same amount of time.

86. What was the effect of the CSA options on your farm production?

1.= Increase production 2= Decrease production 3=No effect on crop production

4. Don't know

87. If the practices increased your production, what did you do with additional production generated with CSA practices?

1.= Mainly use in household consumption 2= Mainly have sold it 3=borrow to other neighbor 4= We use it for both selling and consumption

88. In your option, did this CSA practices generate additional income? 1=Yes 0=No

89. If your answer is yes for q77, how much money you have generated per year in Bir________?

90. For what purpose do you use the income you generated from CSA practices?

1= Buying agricultural inputs

2=Buying food

3=Buying non-agricultural assets

4= Save it

91. Did the CSA option increase food availability? 1=Yes 0=No

92. Did the CSA options helped you to be less affected by climate shocks? 1=Yes 0=No

93. If you answer yes for the above question 81, what is the advantage of implementing CSA practices?

1=Increase production 2= Less inputs use 3= Strong /resilient to climate change

4= Save time 5= other

94. In your understanding how did you perceive about soil fertility status of your cultivated land since you used the above CSA practices? 1= Increased 2= Decreased 3= No change 4= I do not know

95. In your understanding, over all annual income since you used the above CSA practices?

1= Increased 2=Decreased 3= No change 4=I do not know

96. Please indicate frequencies of selected farm management practices per farming systems at both CSA practices and without CSA practices

Please indicate the frequency of applying in number 1,2,3,4,5	CSA adoption	Non-CSA adoption
Frequency of ploughing		
Frequency of weeding		
Frequency of fertilizer application		
Frequency of pesticide application		
Frequency of insecticide application		

H: Food consumption Score

97. Over the last **seven days** (one week) how many days did you consume the following foods?		98. In the **past 30 days** (one month), did your household have access to food? **Choose of the three codes below** **1= Rarely** (once or twice in the past four weeks) **2 = Sometimes** (three to ten times in the past four weeks) **3 = Often** (more than ten times in the past four Weeks		
Items	**Number of days (1-7days)**	Qs	Items	**Codes (1,2,3)**
Cereals (Maize, Teff, Wheat Sorghum, Millet) and tubers (potatoes, sweet potatoes)		1	Did you worry that your family would not have enough food? **1=Yes 0=No** **if Yes, how often did this happen**	
Pulses and nuts (beans, lentils, peas, peanuts, etc.)		2	Not able to eat the kinds of foods you Preferred because of a lack of resources? **1=Yes 0=No** **if Yes, how often did this happen**	

Vegetables		3	Eat limited variety of foods **1=Yes 0=No** if **Yes,** how often did this happen	
Fruits		4	Eat foods that you did not want to eat**1=Yes 0=No** **if Yes, how often did this happen**	
Meat and fish (Beef, goat, poultry, pork, eggs and fish)		5	Eat a smaller food because there Was not enough food?	
Dairy products (milk, yoghurt, cheese, other milk's products)		6	Did you eat fewer meal in day because there was not enough food? 1**=Yes 0=No** **if Yes, how often did this happen**	
Sugar, honey		7	No any kind food to eat in the house? **1=Yes 0=No** **if Yes, how often did this happen**	
Oil, fat, butter		8	Go to sleep hungry because there was not enough food? **1=Yes 0=No** **if Yes, how often did this happen**	
		9	Go a whole day and night without eating? **1=Yes 0=No** **if Yes, how often did this happen**	

99. What are the coping strategies you have used to minimize food insecurity during food shortage time in your households? Please tick under each choose

No	Coping strategies	**(1) =Never**	**(2) =Once in a week**	**(3) =2–6 days/week**	**(4) =Every day**
1	Eating less preferred foods				
2	Borrowing food or relying on help from friends and relatives				
3	Limiting portion sizes at meal times				
4	Selling asset and Purchase food				
5	Limiting adult intake so that small children can eat				
6	Reducing the number of meals per day				
7	Consume seed stock held for next season				

J: CSA practice (<u>Choose one which was the most practiced in your plot</u>: Soil and Water Conservation; Improved Crops, Crop Rotation, Agroforestry, Improved Breeding, Controlled Grazing, Residue Incorporation, Cover Crops, Cut and Carry System)

100. Name of practice you have implemented in your farm plot__________________________?
101. How long have you practiced the above CSA activity in your farm? ……… years
102. What is the lifetime of the selected practice ……………years?
103. What is the total size of your farm covered by the selected practice? ……………hectare
104. List the main crops grown by the above selected practice in the below table refer q93

Crop grown by practice	Tick	Size of farm/ha	% sold	% consumed	Season of production 1=kirment 2=bega 3= both	How many times of cultivations per production season 1,2,3
a. Wheat						
b. Barley						

c. Legumes (Beans, peans)						
d. Enset/false banana						
e. Potato						
f. vegetables						
Other						

105. For each crop grown on the above CSA practices, could you please tell us the maximum yield you got after introduction of the CSA practice and without before introduction of the CSA practice?

Crops grown by practice	area/ha	Before CSA practices		After CSA practice	
		Minimum yield (kuntal/hectare)	Maximum yield(kuntal/hectare)	Minimum yield(kuntal/hectare)	Maximum yield(kuntal/hectare)
Wheat					
Barley					
Legumes (Beans, peans)					
Enset/false banana					
Potato					
vegetables					
Other					

Appendix 'G' Leading Question for Key Informant Interview and Focus Group Discussion

You have been identified as a key informant and group discussion participant to participate in this interview because of your position in and understanding of the community.

Your opinion will be very useful in triangulating information from previous studies and individual household interviews. We appreciate this opportunity to talk to you.

CLIMATE CHANGE AND EFFECTS

1. What does climate change mean for you?

____

____

____

____

____

2. From your experience, have there been noticeable changes in the climate of your area? Yes/No?

If yes, what specific changes have you noticed? explain the trend in temperature and rainfall change in your area in the last 30 years compared with the current situation?

____

____

____

____

____

_____

3. Is the change in temperature and rainfall affecting the agricultural activity in the area? Yes / No

4. If yes for Q3, explain how both crop and livestock production is being affected by the change in temperature and rainfall?

Crop production

____

____

____

____

____

____

____

____

Livestock production

____

____

____

____

____

____

5. When did you start to realize or understand these climate change impacts? Mention the specific time period

   ____

   ____

   ____

ADAPTATION STRATEGIES BY FARMERS

6. Do you practice climate change adaptation to minimize these impacts? Yes/No
7. If yes for Q6, please mention which climate change adaptation practices you have been taking

____

____

____

____

____

____

8. Which risks do you face in?

Agricultural and livestock production risks____

____

____

Health and socioeconomic risks

____

__Biodiversity risks

____

Psychological risks

____

Climate risk

____

9. What are your main barriers /constraints to cope with these above risks?

____

10. What motives do you take to cope and adapt these risks?

____

11. Explain the measures they have been taking to minimize the impacts on crop and livestock production?

____

12. What indigenous adaptation actions are likely to be useful in reducing negative impacts and taking advantage of any opportunities get from climate change?

____

USE OF CLIMATE SMART AGRICULTURE PRACTICE

13. List any agricultural and livestock technologies related (new or existing) that could help you to adapt climate change impacts

Agricultural technologies

____-

Livestock technologies

____

14. Do you know climate-smart agriculture practices (የአየር ንብረት- ለዉጥን የሚቋቋሙ ዘመናዊ የግብርና ልምዶች/ዘዴዎች) ? Yes/No

15. IF Yes for Q14 What do you know about these practices; please tell me the details?

16. Which of these practices have you currently implemented?

Have your livelihood sources changed over the last 5 years? Yes or no

If yes, what are the possible causes of the changes in? if the cause of change is related to CSA intervention, mention some of them

17. Which practices have high implementation cost compare to others and why

____
____

18. Which practices have low implementation cost compare to others and why____
____
____
____
____

19. What is the level of increase in productivity, income and food security due to CSA implementation compared to the traditional Practices?

____
____
____
____
____

20. What are the main motivating factor that helps you to implement such CSA practices?

____
____
____
____
____

21. What are the main challenges that influence you to adopt such CSA options in your farmland?

____
____
____
____
____

22. What are the external effects resulting from implementing the CSA practices? Specifically,

a. Which practices are useful for improving air equality?

____
____
____
____

b. Which practices are useful for nitrogen fixing?

____
____
____
____

c. Which practices are useful for social benefits?

____
____
____
____

d. Which practices are useful for the quality of the environment (natural beauty)?

____
____
____
____
____
____

e. Which practices are useful for improved water availability?

____
____

f. Which practices are useful for the reduction of soil erosion?

g. Which practices are useful for increase soil biodiversity?

h. Which practices is useful for increase crop biodiversity and others?

23. What is expected from the local stakeholder /government /NGOs /to improve the CSA intervention

-

24. What are the main challenges of livelihood improvements in Doyogena wereda