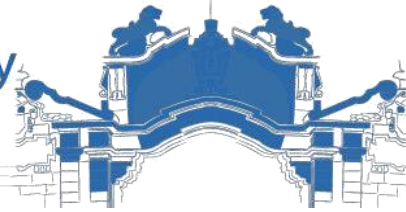




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Mapping Temperature and Rainfall Variabilities/Change and Role of Climate-Smart Agriculture on Food Security and Household Welfare in the Mixed Farming System of Southwest Ethiopia:

A case study from Geshy Watershed

By Girma Tilahun

Supervisors:

Amare Bantider (PhD, Asso. Prof)

Desalegn Yayeh (PhD, Asso. Prof)

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A thesis submitted in fulfillment of the requirements of the degree of Doctor of Philosophy in
Food Security and Development

Center for Food Security Studies

College of Development Studies

Addis Ababa University

Addis Ababa

Ethiopia

2023

DEDICATION

To my children (Hemen Girma and Menkir Girma) who joined this planet right after the beginning of the PhD study and my Loving wife (Maritu Dagnaw), the truly gift from above.

DECLARATION

I, Girma Tilahun Getnet, declare that;

1. This dissertation report, except where indicated otherwise, is my original research,
2. This dissertation has not been submitted for any examination or degree at any other institution,
3. This research does not include the other author's statements, data, graphs, images, or other information unless properly acknowledged. In quoting other written sources, their words are not directly re-written, but the overall information attributed to them has been referenced,
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Name: Girma Tilahun Getnet

Signature:_____

Date:_____

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DISSERTATION APPROVAL

This is to certify that the thesis prepared by Girma Tilahun Getnet entitled “*Impact of Climate-Smart Agriculture on Food Security and Household Welfare in the Mixed Farming System of Southwest Ethiopia: A Case Study from Geshy Watershed*” and submitted to the Center for Food Security Studies in fulfillment of the requirements for the Degree of Doctor of Philosophy in Food Security and Development complies with the regulations of Addis Ababa University and meets the accepted standards with respect to originality and quality.

Approved by Board of Examiners

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EXECUTIVE SUMMARY

In Ethiopia, smallholder farmers whose livelihoods are relying on rain-fed agricultural systems face multiple challenges which include low soil fertility, insufficient capital to purchase inputs, disease outbreaks, pests, and low productivity due to climate change. Climate change has induced changing rainfall patterns and reduced rainfall amounts, prolonged droughts, and threatened the well-being of agricultural-based households. To address the negative effects of climate change, climate-smart agriculture (CSA) technologies have been promoted in Ethiopia. However, the adoption of CSA has been low and on a small parcel of land to date. Thus, scaling up the adoption and ensuring maximum benefits from CSA requires a better understanding of the determinant factors with smallholder farmers. This study aimed at mapping trends and variabilities of rainfall and temperature and impacts of climate-smart agriculture (CSA) on food security and household welfare whereby CSA is currently promoted as a best strategy to reduce climate change impacts on agriculture worldwide. Data collection followed a cross-sectional survey of 384 respondents using systematic random sampling techniques from Geshy watershed in Southwest Ethiopia. Additionally, eight focus group discussions (FGDs) and fifteen key informant interviews (KIIs) were also conducted for validating and triangulating the household survey data collected. Multinomial Endogenous Switching Regression model, multivariate statistical techniques of principal component analysis and cluster analysis as well as the Cragg double hurdle model were used for data analysis.

Based on the PCA-Clustering analysis, the findings revealed that the adoption patterns of CSA differed across typologies of households. Experienced and resource-endowed farmers have a higher level of technology use such as small-scale irrigation and crop rotation that demand more resources while resource-constrained clusters opted out of resource-intensive CSA technologies. The Cragg double hurdle model findings revealed that CSA adoption has significantly been influenced by education level, the share of livestock income, asset ownership, access to market, and price of inputs. The intensity of adoption is significantly affected by factors such as labor size, sex of household head, access to credit facilities, on-farm income, distance to output and input markets, and small-scale irrigation. In light of these results, policies that ensure access to credit and access to market linkage could encourage farmers to adopt CSA technologies. In addition, the efforts of the government must be directed towards decentralization of the input market which can

be accomplished through private sector policy incentives that can bring markets closer to farmers. Access to road in rural areas also incentivizes farmers to improve the adoption of CSA. On the other hand, it can attract potential traders to rural areas. The results of the multinomial logistic selection model showed that observable market access and household characteristics affect the likelihood of adoption of three identified prominent bundles of technologies/combinations by farming households. The findings indicated that household characteristics (labor size and sex of the household head), farm characteristics (soil fertility), and institutional factors (access to credit, market access, and information access) are the major factors determining the adoption of a combination of various CSA technologies. The findings encourage the government to formulate policies aiming at improving farmers' CSA knowledge. The policies may include early warning programs and systems that promote access to the market, information, and credit. The Endogenous Switching Regression econometric model revealed that land size and access to inputs had significantly affected farmers' decision to adopt CSA. The Average Treatment effects of the treated (ATT) and the Untreated (ATU) were significantly and positively different between adopters and non-adopters, respectively showing that CSA adoption has resulted in a significant positive effect on the welfare of farmers. The outcome analysis showed that farm and farmer characteristics as well as market factors significantly influenced household welfare. The income of households with reference to adoption was significantly influenced by factors such as labor size, level of education of household head, TLU, asset index, and off-farm income. On the other hand, food security was significantly affected by factors such as the level of education of household heads, small-scale irrigation, Tropical Livestock Unit (TLU), access to input-output market, and access to water and sanitation. The findings call for development practitioners to integrate market linkages that bring buyers and traders closer to farmers. Findings of the multi-objective programming model suggest minimizing the general field croplands and focusing on high-value horticultural crops, poultry, and ruminants. In conclusion, the adoption of CSA can help improve food security, household welfare and reduce adverse climate change impacts. The integration of CSA approach into the agricultural policy of Ethiopia is then recommendable.

LIST OF ACRONYMS

AAU	Addis Ababa University
ATE	Average Treatment Effect
ATT	Average Treatment effect of the Treated
ATU	Average Treatment effect of the Untreated
CA	Conservation Agriculture
CCAFS	Climate Change, Agriculture and Food Security
CGIAR	Consultative Group for International Agricultural Research
CIAT	International Center for Tropical Agriculture
CIMMYT	International Maize and Wheat Improvement Center
COMP	Component
CSA	Climate-smart agriculture
CV	Coefficient of Variation
DT	Drought Tolerant
DTMA	Drought Tolerant Maize for Africa
GDP	Gross Domestic Product
EIAR	Ethiopian Institute of Agricultural Research
E.G.	Example
ERR	Error
ESR	Endogenous Switching Regression
FANTA	Food And Nutritional Technical Assistance
FAO	Food and Agricultural Organization of the United Nations
FCS	Food Consumption Score
FGD	Focus Group Discussion
GDP	Gross Domestic Product
GGGI	The Global Green Growth Institute
GHG	Green House Gas
GHI	Global Hunger Index
HA	Hectare
HDDS	Household Dietary Diversity Score
HH	Household
HFIAS	Household Food Insecurity Access Scale

IDW	Inverse Distance Weighted
I.E.	That is
IEC	Information, Education, and Communication
IIA	Independent Irrelevant Alternatives
IITA	International Institute for Tropical Agriculture
INDDEX	International Dietary Data Expansion
IPCC	International Panel on Climate Change
ISSD	Integrated Seed Sector Development
K/cals	Killo calories
KII	Key Informant Interview
KMO	Kaiser-Meyer-Olkin test
MASL	Meters Above Sea Level
MK test	Mann Kendall test
MNLESR	Multinomial Endogenous Switching Regression
N	Nitrogen
NGO	Non-Governmental Organization
NMA	National Meteorological Agency
OLS	Ordinary Least Squares regression
P	Phosphorus
PCA	Principal Component analysis
PCI	Precipitation Concentration Index
PSM	Propensity Score Matching
SEM	Structural Equation Model
SIMLESA	Sustainable Intensification of Maize-Legume Cropping System for Food Security in Eastern and Southern Africa
SPSS	Statistical Package for Social Science
SSA	Sub-Saharan Africa
STD	Standard
TLU	Tropical Livestock Unit
UNEP	United Nations Environmental Program
UNFCCC	United Nations Framework Convention on Climate Change
WFP	World Food Program

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CHAPTER 1: GENERAL INTRODUCTION

GENERAL INTRODUCTION

1.1 Background and Justification

The livelihood of about 2.5 billion people of the global population relies on rain-fed crops, livestock, and fishery sectors all vulnerable to climate change (Rojas-Downing et al., 2017). In a report by the Intergovernmental Panel on Climate Change (IPCC), Africa is experiencing a rise in temperature by about 0.03°C per year since 1975 and more extreme weather such as droughts, heat waves, and floods (Trisos et al., 2022). Due to the reliance on rain-fed agriculture, farmers are highly affected by these changes and extremes. Climate-smart agriculture (CSA) can help farmers address these climate-induced-agricultural effects such as reduced rainfall amounts, prolonged droughts, and rainfall pattern changes which have adverse impacts on crop and livestock production (Abegunde et al., 2022; Escarcha et al., 2018; Radeny et al., 2022; Shikuku et al., 2017). The concept of CSA was first introduced by the United Nations Food and Agricultural Organization (FAO) in 2010 to outline a set of technologies relevant to improve agricultural productivity within the context of national development goals and food security (FAO, 2013). These CSA technologies refer to agricultural practices that increase productivity sustainably, build adaptation (resilience), and remove or reduce greenhouse gas emissions (mitigation co-benefits) (Lipper et al., 2018; Rafik et al., 2022). CSA comprises three pillars namely productivity, adaptation, and mitigation, which are also termed triple wins. Some examples of CSA practices include integrated soil fertility management practices such as intercropping cereals with legumes, crop rotation, organic fertilizer (Gram et al., 2020; Partey et al., 2018), short maturing and drought-resistant varieties (Ogada et al., 2020), improved animal husbandry and agroforestry practices (Musafiri et al., 2022; Partey et al., 2018), conservation agriculture (Autio et al., 2021), and soil and water conservation practices (Zougmore et al., 2014) among others. Climate-smart agriculture contributes to poverty reduction, food security, and economic development in farming households demanding food and land expansion challenges (Leocadio et al., 2019; Zougmore et al., 2018). These technologies of CSA can maximize crop and livestock productivity while improving farmers' welfare and reducing resource degradation in the face of climate change (Branca & Perelli, 2020; Leocadio et al., 2019).

In Ethiopia, smallholder farmers constitute 95% of the agricultural output, and the adoption of improved agricultural technologies is key for ensuring food security and livelihood development

(Tigre & Heshmati, 2022). Thus, agriculture plays a considerable role in the economy. It contributes 85% of foreign exchange, 52% of GDP, and 80% of employment (National Bank of Ethiopia, 2022). The productivity of agriculture has been emphasized in all development policies of the country to address challenges faced by smallholder farmers. The average landholding size of Ethiopian smallholder farmers is 0.96 ha, which is very small by international standards (Headey et al., 2014). The definition of smallholders is small-scale farmers, pastoralists, forest keepers, or fishers that manage areas varying from less than one hectare to 10 hectares (Ricciardi et al., 2018). Low-input-low-output agricultural practices are common phenomena among smallholder farmers in Ethiopia. The amount of input used is far below the recommended averages (Tigre & Heshmati, 2022). For instance, the amount of fertilizer used showed an increase from 1996 to 2018 with 12kg/ha to 36.2kg/ha, respectively. This figure though higher than the sub-Saharan countries' average fertilizer nutrients use, which is 17 kg/ha, is yet much below the global average, which is 135 kg/ha (Abebe et al., 2022; Tigre & Heshmati, 2022). The country is also ranked 104th out of 121 countries in the 2022 Global Hunger Index (GHI) with a score of 27.6 and categorized under the serious food insecurity category (GHI, 2022). In rural Ethiopia, the patterns of food security are seasonal and linked to rainfall patterns, drought occurrence, and other extremes, which makes the agriculture sector and food security situations vulnerable to climate change impacts (Mekonnen et al., 2021). *Ceteris paribus*, climate-smart agriculture can therefore provide significant benefits to farmers to minimize the negative impacts of climate change. The government of Ethiopia developed a national CSA roadmap in 2020, which was ratified by the Ministry of Agriculture. It provides important insights into the foremost significance of agriculture for the country, vulnerabilities, and key risks that the food systems and farming livelihoods face in the changing climate (Eshete et al., 2020). The diverse practices included in this road map are conservation agriculture, integrated soil fertility management practices, small-scale irrigation, agroforestry, crop diversification, improved livestock feeding practices, and improved animal husbandry practices that are important to improve food security and enhance rural household welfare (Eshete et al., 2020).

Among these practices, for instance, the rate of adoption of improved dairy farming practice on a small parcel of land is less than 3% in the country (Diro et al., 2022). Socioeconomic assessments of the different adoption of CSA technologies in smallholder farming societies can be vital to farmers, policymakers, and researchers so that impacts (Kifle et al., 2022; Negera et al., 2022;

(Kassa & Abdi, 2022; Meshesha et al., 2022; Diro et al., 2022) are known and determinants of adoption (Agbenyo et al., 2022; Branca & Perelli, 2020; Lipper et al., 2018) for various household typologies are also described to inform scaling up of adoption strategies.

In Ethiopia, rain-fed agriculture is the main source of livelihood for smallholder farmers. A complexity of several socioeconomic and bio-physical challenges are confronting farmers leading to low productivity, which in turn leads to poor livelihood and food insecurity and low household income. Yield reduction is often associated with abiotic factors (drought, declining soil fertility, change in temperature, and heat waves) and biotic stresses (leaf rust, maize lethal necrosis, leaf blight, grey leaf spot, *Striga*, diseases, and pests) (Johansen et al., 1994; Mustafa et al., 2022; Pandey et al., 2017). Additional factors that contribute to low productivity include poor farming practices such as mono-cropping, land tenure insecurity, poor varieties, population growth, poor governance in input supply, and dependency on rain-fed agriculture in the face of climate change. Climate change's debilitating effect adds to the existing challenges encountering smallholder farming systems. As highlighted by the Alliance for Green Revolution in Africa (AGRA), climate change is worsening the already resource-constrained smallholder farmers' situation, with more extreme weather and erratic weather events, reducing the already low productivity (AGRA, 2021). A range of climate shocks challenges the smallholder farming system to the extent of posing far-reaching costs for future food production. Uncertain and rapid rainfall changes and temperature patterns increase smallholder farmers' vulnerability, impend food production and accelerate rural poverty (Hansen et al., 2019; Li et al., 2022). Temperature and precipitation in Southwest Ethiopia, though is known as the wettest parts of Ethiopia, is nowadays experiencing warmer temperatures and reduced precipitation trends (Gemedda et al., 2021; Teshome & Zhang, 2019) that indicated an increase in 0.25°C/decade over the study period (1981-2020), a condition that could lead to an increase in drought risk. These negative projected effects of climate change call for swift actions that can reduce their potential impacts on farming livelihoods.

One of the possible strategies to improve productivity and enhance household income is the adoption of CSA technologies (Ogada et al., 2020). In on-station and on-farm trials, CSA practices were proven to increase productivity over the years but the level of adoption of these technologies is yet minimal (Negera et al., 2022; Welteji, D. 2018). Given the model prediction that countries like Ethiopia will experience further warming (Gemedda et al., 2021), farmers should consider CSA

technologies that have the potential to enhance or maintain household food security. The situation of food, income and livelihood insecurity will get worsen for smallholder farmers without adopting CSA technologies. This fact precipitates the need to recognize factors that are constraining CSA technologies adoption, their impact on household income, and food security, which are important indicators of welfare.

The real magnitude and nature of the effects of adopting CSA technologies are not well investigated, particularly in Ethiopia. One justification for this is that most researchers study a single CSA technology without recognizing that farming households may adopted several technologies simultaneously. A second research gap is that the whole farm system (crop-livestock-vegetation) effect of CSA has not been studied as the majority of studies concentrated on a single technology impact on crop production. Similarly, information on households with heterogeneous resource endowments of mixed farming system impacts of CSA is lacking. Thirdly, many studies dealing with CSA technologies focus on estimating adoption as being a dichotomous variable with binary options i.e. adoption or non-adoption.

Most of the available studies in Ethiopia that focus on the effect of agricultural technologies on household food security are marred by univariate analysis (Getaneh et al., 2022; Tesfayohannes et al., 2022; Lejissa et al., 2022) of single food security dimension with single climate agriculture technology. However, research can go beyond the dichotomous dependent adoption variable to identify CSA technologies of diverse combinations currently adopted by farmers. Most studies consider different factors influencing the likelihood of adoption of CSA practices. The fact, however, indicates that decision-making processes related to innovation adoption involve a multi-stage procedure including the level of adoption (intensity), when to adopt, whether or not to change conventional technologies as well as for which enterprise (Gebru et al., 2021; Wordofa et al., 2021). Therefore, the contribution of this research to the present literature is the provision of a hybrid model for the adoption of CSA that takes into account various factors influencing multiple CSA technologies adoption at two levels i.e. level of adoption and decision to adopt. Technologies of CSA are probably to be adopted when farmers achieve benefits in terms of e.g. improved consumption and higher income prospects. The benefits of CSA technologies have usually been measured in biophysical terms such as soil fertility, and yields (Junia Mutenje et al., 2019; Kifle et al., 2022) and impacts on household food security and income received less attention. The study

thus investigated spatiotemporal variabilities and trends in temperature and rainfall and their implications on CSA, the impact of CSA technology adoption on household welfare, and influencing factors affecting CSA technology adoption. Lastly, given the resource scarcity, synergies and trade-offs of adopting CSA technologies in achieving household goals were investigated in the Geshy watershed of Southwest Ethiopia.

1.2 Objectives

The overall objectives of this study is to analyze spatiotemporal variabilities and trends in temperature and rainfall, and evaluate the impact of CSA technologies adoption on food security and household welfare in the Geshy watershed of Southwest Ethiopia.

Specifically, the explicit research objectives are:

1. To analyze the spatiotemporal variabilities and trends of temperature and rainfall (1980-2020) and its implication to CSA
2. To investigate the current level of adoption of CSA technologies among farmers in a mixed crop-livestock farming system across various household typologies
3. To identify the patterns and determinants of CSA adoption among household typologies at the farm level
4. To compare the household food security situation of adopters and non-adopters of multiple CSA technologies
5. To analyze the effects of adoption of CSA technologies on household welfare, measured by household food security and income
6. To investigate the synergies and trade-offs of CSA technologies on the three pillars of CSA (productivity, adaptation and mitigation)

1.3 Description of the study area

1.3.1 Geographical location of the study area

This study was conducted in the Geshy watershed, which is part of the Gojeb river catchment of the Omo-Gibe basin in Ethiopia (Fig. 1). Administratively, the watershed is located in Gimbo Woreda of Kaffa Zone. It is geographically located between 7°26' N and 7°21' N latitude and

between 36°15' E and 36°23' E longitudes which makes the entire area of 13,935 ha with an altitude ranging from 1,200 to 2,670 m.a.s.l.

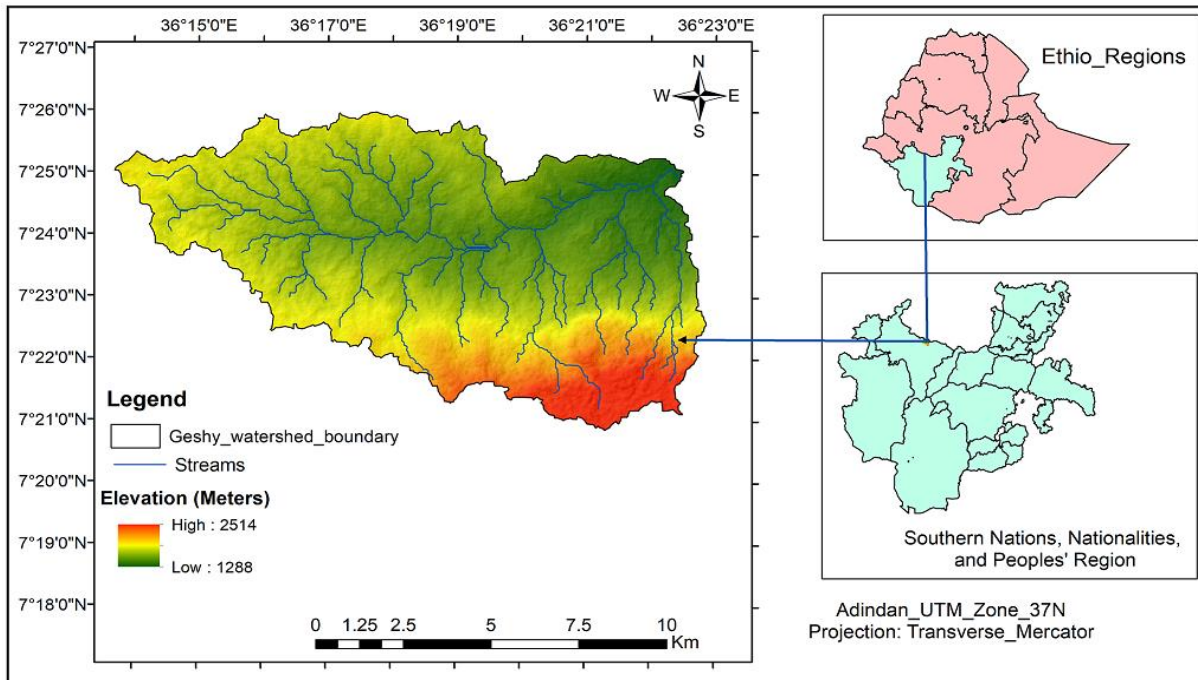


Figure 1: Location map of the study area

(Source: own development)

The study area was selected based on its representativeness in promoting and implementing CSA practices by the local government, which is supported by the World Bank. As part of the Ethiopian Strategic Investment Framework (ESIF), the World Bank supports about 177 participatory watersheds in the country including Geshy watershed through its Sustainable Land Management Project (SLMP) I and II. It aims at reducing land degradation and improving agricultural production. The promotion and implementation of CSA was one of the approaches used to address these objectives (World Bank, 2020). Further, CSA practices have also long been practiced in the watershed by smallholder farmers traditionally. Even if they cannot tell you the three pillars of CSA, they have good reasons for doing so and they inadvertently fall within the three pillars.

1.3.2 Socioeconomic background

Nine *Kebeles* (the lowest administrative unit) are beneficiaries of this watershed with a total rural population of 14,518 of which 7,261 are males (CSA, 1996). During the national resettlement program in

Ethiopia in 1985, the area was selected as a potential resettlement site for affected people, especially from Northern Ethiopia which constituted 64 percent of the population.

The major economic activity is based on agriculture. With an estimated area of 13,935 ha, the main agricultural crops are maize (*Zea mays*), enset (*Ensete ventricosum*), and teff (*Ergrostis tef*) accounting for 41.9% of the total landmass. Natural forests (8.98%), degraded hillside land (2.6%), woodlots (8.48%), and the remaining other small fragments of land cover the remaining areas of the watershed. The indigenous people also use non-timber forest products (NTFPs) such as false cardamom (*Aframomum corrorima*), honey, and wild pepper (*Piper capense*) as an important source of household income. The forest is also used as a source of charcoal, fuelwood, and timber. The most important cash crop is coffee, which farmers collect and manage inside the forest and plant it in their home gardens.

Besides collecting coffee and spices from the natural forest, smallholder farmers also plant enset, bananas, haricot beans, and maize in their homesteads. Nowadays, to address the food and income demands of their households, farmers are illegally and traditionally practicing expansion of agricultural land by reducing the forest area. This put great pressure on the natural forest reserve (Kumar et al., 2020).

1.3.3 Biophysical environment

1.3.3.1 Climate

The area falls under sub moist mid-highland to warm moist highland climatic zones. This diverse zone enables the sub-watersheds to produce different crops, fruits, vegetables, and rearing livestock (Moges & Bhat, 2021). It has an average annual rainfall ranging between 1,200 to 2,200mm; while the average monthly minimum temperature ranges between 8°C to 13°C maximum and the average monthly temperature ranges between 12°C to 26°C (Fig. 2) (Girma et al., 2023). The distribution of rainfall is bimodal in nature and the main rainy season occurs mostly from June to mid-November, locally called *Kiremt*, and February to May is another season with light rain, which is locally known as *Belg* leading to two harvesting seasons (Gemedo et al., 2021). Early cessation, a delayed onset, abundant rainfall, and poor *Belg* performance make the watershed food insecure and force farmers to shift to livestock production and grow short-maturing and lower-yielding varieties.

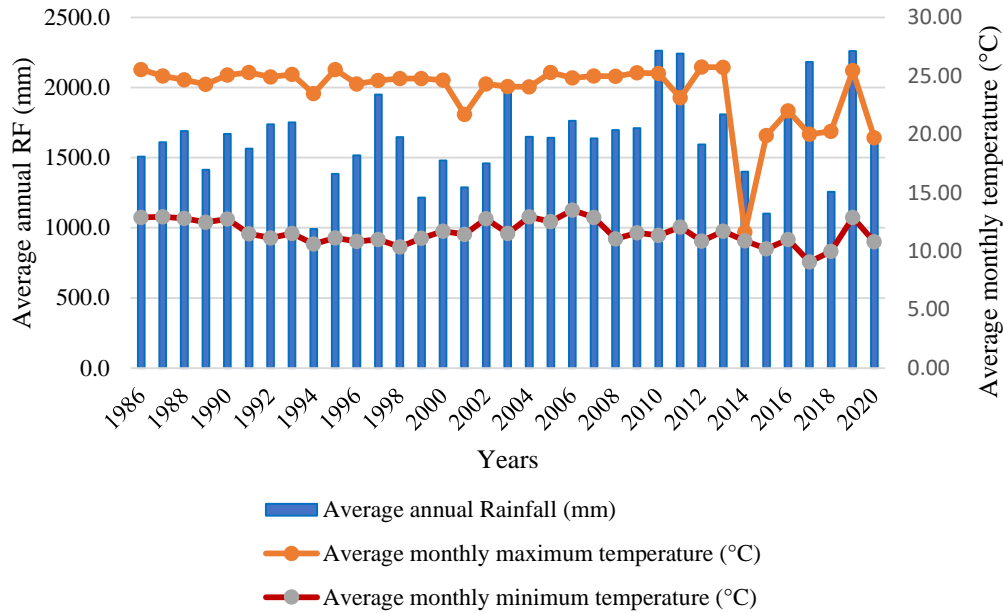


Figure 2: Average annual rainfall (mm) and average monthly minimum and maximum temperature (°C) of the study area (1986-2020)

1.3.3.2 Geology, topography and soil

The Southwestern montane rainforest area is one of the biodiversity hotspots in East Africa and the center of origin and diversity of wild *Coffea arabica* on which the study area is the part (Dennis, 2017). The underlying basement rock consists of faulted and folded Precambrian rocks, layered by tertiary basalt traps and Mesozoic marine strata (Dagnachew et al., 2019). The slope of the study area ranges from 10% to 60%. Due to the high rainfall (over 2,200 mm/year) and the nature of the topography, the soil is exposed for erosion. Much of the fertile soil is then tied-up in the top 20cm horizon and the fertility of the soil is maintained through nutrient cycling between the soil and the living forest vegetation (Tezera, 2017). Deforestation contributes to rapid decline in soil fertility. The dominant soil types are Cambisols, Vertisols, Regosols, Fluvisols, and Leptosols (Dagnachew et al., 2019). The pH of the soil ranges from 5.3 to 6.6 and is categorized as acidic.

1.3.3.3 Flora and Fauna

The study area is located in one of the tropical evergreen montane forest areas of Southwest Ethiopia. The landscape, which was formerly densely forested, presents bamboo thickets, primeval forests and wetlands. The dominant tree species include *Coffea arabica*, *Pouteria adolfi-friedercii*, *Berasama abyssinica*, *Schefflera abyssinica*, *Trilepsium madagascariense* and *Polyscias fulva*. Among the hundred recorded bird species in the area, fifteen of them are reported and characterized

as “Highland Biome Species”, thus accounting for 31% the Restricted Highland Biome Collections in Ethiopia (Tezera 2017). The forest ecosystem makes a crucial contribution to people’s livelihoods in the area. It provides commercially valuable spices, wild coffee, and honey from wild bees.

1.4 Research methodology

1.4.1 Research philosophy

The idea that there are various views of the world, and the operating processes within it, is part of what is termed as philosophy. Research philosophy is thus the set of beliefs regarding the nature of reality under investigation and the choice of the applied type of research philosophy in an area of research rely on the knowledge being investigated (Bonache, 2020). Thus the perception of reality and the way knowledge was gained affect the way this study was conducted.

Ontology and epistemology are the two most research philosophy paradigms used to view reality and gain knowledge, especially in social research (Hellman, 2021). Ontology concerns with the question , “what is real?” and epistemology deals on the responses to the question “what is real?” influences the way in which knowledge is obtained (Hellman, 2021). In light of this, those who believe there are universal truths that are waiting to be discovered, are usually referred to as ‘positivists’ (Matta, 2022). On the other hand, ‘constructivists’ or ‘interpretivists’ are those that believe there is no reality other than what individuals create in their minds (Matta, 2022).

This study adopted the positivist philosophical approach of research based on the central idea that the adoption of CSA practices improves food security and adaptation capacity of rural smallholder farming households. Because the study conducts an objective investigation of reality by explaining the research objectives and on the basis of the conviction that household respondents could not be obstacles through the process of the research. This cause-effect relationship study employs a quantitative method through gathering and converting data into numerical statistical analysis and this approach is generally associated with positivism (Matta, 2022).

The researcher also argues for the use of an interpretivist philosophical approach in analyzing the determinant factors for CSA practices adoption by smallholder farmers. Through the process of examining factors influencing CSA adoption, the perception of farmers towards a certain CSA practice matters most. Perception is again a function of different variables including level of

education, age and gender among others (Diro et al., 2022). Individualistic views and perceptions determine the knowledge towards a certain CSA practice adoption and is a typical characteristic of subjective generalization that define interpretivism approach (Matta, 2022).

1.4.2 Research design

This study adopted a cross-sectional research design with a mixed (qualitative and quantitative) research method. A cross-sectional research is adequate for generation of important data, the analysis of, drawing inferences from, available differences between subjects, people or phenomena. Cross-sectional research design can use data from contrasting observational studies and diverse backgrounds of disciplines. Comparatively, it is less time consuming and less expensive to use (Wang & Cheng, 2020). For this study, cross-sectional research design was considered to be appropriate because it enables sound and rational conclusions, coupled with its cost and time-efficiency. The rationale for the selection of this research design is to get precise investigation into the research problem to gain a better understanding into the causes, factors, and potential outcomes of CSA practices adoption in small-scale agricultural systems, even with money and time constraints. In addition, the use of cross-sectional design allows the use of open and close-ended questionnaires of structured interviews as a research tool in this study. The open and close-ended questionnaire of the structured interview helped data collection and conversion into a numerical form for drawing inferences and statistical analysis. The design provides empirical evidence on the underlying causes, influencing factors and outcomes of CSA adoption. This study utilizes both inferential and descriptive statistical analysis for drawing robust conclusions.

1.4.3 Source of data, type of data and data collection method

This study used secondary data analysis and survey method for data collection. The secondary data analysis was the available climatic data between 1986 to 2020, which was obtained from the National Meteorological Agency (MNA). On the other hand, survey method of primary data collection was undertaken using close and open-ended questionnaires through structured interviews. The questionnaire were used to reveal empirical evidence from the study by eliciting detailed information for descriptive and inferential analysis. The appropriateness/relevance of the questionnaire were pretested with 38 smallholder farmers. This size of sample was taken in line with Viechtbauer et al. (2015) and Lewis et al. (2021) studies who recommended a 10 percent

sample for pilot study from the actual sample size. The questionnaire were pre-tested for appropriateness, adequacy, and effectiveness of the questions in collecting the accurate data needed for analysis. Attention was also given to the time taken to complete the questionnaire while pre-testing it. The respondents employed for pretest of the questionnaire did not take part in the actual survey. The researcher also conducted a detailed key informant interview and focus group discussion to gain a better insight of the typology (homogeneity/heterogeneity) of the target group, validate the data collected through questionnaire and also identified key issues affecting CSA adoption in the system.

Data collected for farm activities and related information was for the preceding farming season to ensure regularity, uniformity and completeness of the dataset. The survey data collection was conducted at household level. The actual respondents were the individual (s) responsible for each household farming activities. This method enabled to obtain quality information and robust response on the farming household agricultural activities. Data were collected on CSA practices, yield on agricultural practices and socio-economic characteristics of farmers (variables considered as set of farmers features such as gender, age, educational level and income) among others.

The questionnaires were interviewer administered to guide against the challenges, misunderstandings or misinterpretations of questions and words. Data collection was carried out during working hours (08h00-17h00), and unusual times including weddings, funerals and social grant pay-outs were avoided. The questionnaires were translated into local language in the study area to get credible, relevant and reliable information and for effective communication from respondents. Prior to taking part in the research, respondents were requested to sign informed consent forms.

1.4.4 Sampling technique and sample size determination

A three-level multistage sampling technique was used to select the location in which the unit of observation (study) consists the required characteristics (Mugenda, 2022). Based on the agricultural potential, climate variabilities and prior CSA practices, the Geshy watershed was purposively selected in using the multi-stage sampling technique. The target population in this study were smallholder farming households that are beneficiaries of Geshy watershed. The identification of the district, where the Geshy watershed is found, was the first stage. Identification of 9 *Kebeles* (the smallest governmental administration unit), which are beneficiaries of the

watershed, was undertaken in the second stage. The third stage follows randomly selecting six villages out of the total twenty two villages for administering the survey data collection. Finally, using sample size calculator (Eq. 1) using 95 percent confidence interval, 384 households that were traditionally practicing various packages of CSA, were identified and distributed to the six villages equally for survey data collection.

$$n = \frac{\frac{z^2 \times p(1 - p)}{e^2}}{1 + \left(\frac{z^2 \times p(1 - p)}{e^2 N}\right)} \quad (1)$$

Where, n = sample size; N = Population size; e = margin error (5%); and Z = z-score (1.96)

This survey data collection, focus group discussion and the key informant interview were carried out between October 2021 and February 2022 by well-trained enumerators and the researcher.

1.4.5 Data analysis method

Spatiotemporal variabilities of temperature and rainfall was analyzed using coefficient of variation (CV) and Precipitation Concentration Index (PCI) whereas trends in temperature and rainfall was analyzed by using Man Kendal test (MK test).

The patterns of CSA adoption among various household typologies was analyzed using principal component analysis. Double hurdle model and Multinomial Endogenous Switching Regression analysis were used to analyze impact of CSA adoption on food security and the determinant factors of CSA adoption.

The impact of CSA adoption on household welfare was also examined using household income and food security indices by analyzing the drivers of CSA adoption through Multinomial Endogenous Switching Regression model.

Synergies and Trade-offs of CSA technologies was analyzed by determining the performance of the top five ranked CSA practices on the three CSA pillars (Productivity, Adaptation and Mitigation) using a spider graph.

The various sections of the research data were analyzed using Statistical Software for Excel (XLSTAT), Statistical Package for Social Sciences (SPSS) 26.0, STATA 15 and ArcGIS 10.7.1 software.

1.5 Significance of the study

Given the huge majority of smallholder farmers' reliance on agriculture for food, income, and livelihood security, and the relatively high contribution of this sector to the national economy, the key to the economic growth of Ethiopia lies in the development of the agricultural sector. Given the challenges posed by climate change, in addition to biotic and abiotic stressors, the adoption of CSA technologies by farmers can play a significant role in the country's development by increasing productivity, creating farmers' resilience to climate change (adaptation) with mitigation co-benefits. It is thus worthwhile to study the extent and nature of adoption to date to inform policy makers to guide their informed policy formulations.

The study seeks to contribute to the body of knowledge on adoption studies by evaluating CSA technology adoption patterns for rural households that are challenged with climate change impacts. Results from this study will be key in categorizing technology combinations being adopted by farmers and justifications given for their choice. Researchers will benefit from this study through classification of adopters and non-adopters and mapping of the currently under-use CSA technologies. The findings will help researchers through the modification of technologies to suit farmers' biophysical and socioeconomic realities and provide relevant inputs for policymakers by identifying the best output-yielding CSA technology combinations, which need to be promoted.

Relevant literature that links adoption, household typology, productivity enhancement, and food security, adaptation, and mitigation in the mixed farming system is also available very few. This study hence strives to bridge the gap. As a result, the study contributes to the present literature in two ways. Primarily, the analysis uses comprehensive cross-sectional data across household typologies. The study discusses the adoption of CSA technologies by farming households. Secondly, the study additionally clusters adoption into popular technology bundles. Contemporary research has used adoption as a binary variable (Kumar et al., 2020; Yigezu et al., 2018; Gebru et al., 2021) which does not indicate the extent of adoption. The study, thus, used the double hurdle model which is run at two levels i.e. decision for adoption and adoption intensity. Also, the study measures the impact of adoption on food security and household welfare (determined by household income and food security). The study winds up by analyzing synergies and trade-offs of the technologies and by modeling the optimal mix suitable for different bundles of technologies. Results from this study will help inform policymakers on the present impact of CSA practices on

food security and welfare and inform farmers on which technology options increase revenue and save more costs of production. The research results also give feedback to research programs on the technologies desired to be promoted.

1.6 Operational definition of terms

Climate change: refers to the natural or human induced changes in the average and/or climate variability properties and that persists for an extended period, typically decades or longer (IPCC, 2019).

Climate change adaptation: refers to the adjustments in social-economical-ecological systems in response to expected or actual climatic stimuli, their impacts or effects (Trisos et al., 2022).

Climate change mitigation: refers to efforts to reduce or prevent emissions of greenhouse gases (UNEP, 2023).

Climate Smart Agriculture: is an approach that helps guide actions to transform agri-food systems towards green and climate resilient practices (FAO, 2023).

Climate-Smart Agricultural practices: defined by FAO as agricultural activity that efficiently and sustainably increases productivity and income (adaptation), removes or reduces Greenhouse gases emissions (mitigation), enhances national food security achievement and sustainable development goals (FAO, 2013).

Climate-Smart Agricultural strategies: a group of related (in terms of use) climate smart agricultural practices (Kassa et al., 2022).

Climate-Smart Agricultural technologies: the application of scientific knowledge to climate – smart agricultural practices in achieving its practical goals in a reproducible way (Diro et al., 2022)

Climate-Smart Agricultural packages: a combination of climate smart agricultural strategies used by farmers in the study area (Abegunde et al., 2022).

Vulnerability: is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes (Trisos et al., 2022).

Smallholder farms: defined as being a land up to 2 hectares and are mainly managed with family labor (Zeresa G., 2021)

Food Security: is a 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).

Household Welfare: refers to the total utility derived from all the goods and services consumed and measured by household food security and income (Mujeyi et al., 2021)

Tropical montane area: an area of, relating to, growing in, or being the biogeographic zone of relatively moist cool upland slopes below timberline in the tropics (Salinas, et al., 2021)

Watershed: refers to a spatially explicit hydrological landscape unit and socio-political-ecological entity which plays crucial role in determining food, economic and social security and provide life support services to rural people (Kumbhar et al., 2012)

1.7 Structure of the research dissertation

The dissertation uses a research article format and divided into seven chapters. Each chapter is mostly autonomous with sections on abstract, introduction, methodology, and results with discussion and conclusion where recommendations are also included where necessary. Chapter 1 is an introductory chapter that outlines the research problem, the rationale, and the research gap that this study is going to address. The chapter also presents the specific objectives. Chapter 1 is then succeeded by chapter 2, which provides an overview of climate change and variabilities, its impact on smallholder agriculture in a mixed farming system in Geshy watershed, Southwest Ethiopia in particular, and to the country in general. It then goes on to discuss CSA that has been tried to be promoted in the study sites. The chapter also reviews similar studies that have been conducted on adoption components and thereof impacts and helps in developing methods that were used in addressing the objectives of the research. Chapters 3 to 6 discuss the empirical findings intended to address the stated objectives and present them in the form of paper format. Chapter 7 provides a conclusion, synthesis and recommends future research focus.

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CHAPTER 2: GLOBAL EXPERIENCES OF CLIMATE-SMART
AGRICULTURE: ITS ROLE ON BRIDGING FOOD SECURITY GAPS AND
REDUCING CLIMATE CHANGE IMPACT

GLOBAL EXPERIENCES OF CLIMATE-SMART AGRICULTURE: ITS ROLE ON BRIDGING FOOD SECURITY GAPS AND REDUCING CLIMATE CHANGE IMPACT

2.1 Abstract

Climate-smart agriculture (CSA) is progressively being promoted by development institutions, governments and research organizations to maximize productivity, increase resilience of livelihoods and farming systems (adaptation), and minimize or reduce greenhouse gas emission to the atmosphere (mitigation). This review synthesized knowledge on prospects of CSA and climate change in addressing the adverse effects of climate change and variability. The results depict that smallholder farmers in Sub-Saharan Africa are highly impacted by climate change/variability due to their reliance on rain-fed agriculture production system. From the basket of available CSA technologies in the study area, the review found that small-scale irrigation is the dominant option promoted besides improved animal husbandry and improved crop varieties technologies. Secondly, adoption differs across typologies of farmers and hence there can never be one-size-fits-all approach during adoption promotion in farming societies. Thirdly, the key in spearheading adoption of CSA is the active involvement of all actors along the value chain from the buyers to input suppliers of agricultural commodities. Moreover, the review indicted that development partners and the government have played a crucial role as evidenced by the Ethiopian CSA roadmap that supports CSA initiatives. In a nutshell, currently available empirical research evidences are limited that argue the adoption and impact patterns of distinct technologies with limitations on measuring combination of technologies and modelling optimal mix for smallholder farmers who are advised to adopt various CSA combination of technologies.

Keywords: climate-smart agriculture, climate change, CSA roadmap, Geshy watershed

2.2 Introduction

This chapter reviews recent literature related to climate-smart agricultural technologies, including impact and adoption. Climate change is proven to be an effective barrier to agricultural development in a number of regions, especially in the context of developing countries that are heavily reliant on rain-fed agriculture (Aryal et al., 2020; Emediegwu et al., 2022). Climate change affects food security negatively and is impacting the livelihoods of millions of smallholder farmers in Sub-Saharan Africa. Future projections of climate change for the Sub-Saharan region are even pointing to a warning trend, defined by frequent extreme heat waves occurrences (standard deviations of temperature 3 and 5 above the historical norm), changes in rainfall and increasing aridity (a decrease in wet days by 15%-45% for Southern Africa and an increase by 50% to 100% in very wet days in eastern tropical Africa in 2018). In turn, agriculture is also the source of 19% to 29% of greenhouse gas (GHG) emissions. These changes have generally negative impacts on crop yields with worst-case scenario projections showing losses of legumes of about 27% to 32% (e.g. beans and groundnut) and cereals (sorghum, millet, and maize) for warming more than 2°C (Hasegawa et al., 2022; Sultan et al., 2019). Disease and pest incidence have also been on the rise due to climate change impacts. Globally, insect pests reduce 40% of the world's food supply (Wollenberg et al., 2016). Ethiopia has experienced the emergence of crop pests such as moths, termites, weevils (most severe), and fall armyworms during the 2020/2021 season (Kalsa et al., 2019). These pests if not managed can cause 100% loss. The rise in temperature associated with climate change can further reduce the effectiveness of certain pesticides. This has hence increased water stressed crops vulnerability from attacks by pests.

When there is lack of water, grazing, and drought occurrences, pressure on household labor can be resulted. This increases the household labor time required in looking for water and grazing and eventually reduces the time for other farming activities (e.g. crop cultivation activities) and household practices (food preparation, household care, leisure, etc.) (Silva et al., 2019). Heat stress has also negative impacts on livestock production on a variety of parameters of production. The highest parasite abundance and disease incidence can occur due to warmer temperatures. Transmission of pathogenic micro-organisms, the proliferation of ticks and mosquitos as well as the shorter rate of development can be promoted by higher temperatures (Godde et al., 2021). In Ethiopia, tick-borne diseases such as anaplasmosis, babesiosis, theileriosis, and dermatophilosis resulted in significant losses among livestock (Fesseha et al., 2022). All these changes will thus

negatively influence household food security and income. These effects will be felt in markets and food prices, agriculture and income of rural communities, and in other various sections of the food system (e.g. safety, food quality, and storage). Vulnerability reduction of the agricultural system due to climate change and extreme weather conditions as well as strengthening the adaptive capacity of the agricultural system are relevant prerequisites that must be addressed if agriculture has to play its full potential to ensure household food security. Minimizing emissions contributing to global warming are also important in global wellbeing security. The agricultural sector therefore has considerable capacity to minimize emissions while concurrently play its crucial role in ensuring food security and reducing poverty. Taking in to account climate change impacts are felt differently within and between regions, building the adaptive capacity of smallholder farmers and reducing risks can be achieved through context-specific adaptation measures. Therefore, climate-smart agriculture has been promoted to adapt smallholder farmers to climate change and variability with mitigation co-benefits. This review, then provides an up-to-date information of CSA in Sub-Saharan Africa, Ethiopia, and Geshy watershed. It highlights its impact and adoption on food security and household welfare. In addition, it discusses how to measure impacts and adoption.

The literature review explored recent information and knowledge in Sub-Saharan Africa and Ethiopia about the status of climate change, its impacts, adoption patterns of CSA, and how it is promoted. Moreover, the review discusses the impact of theoretical models on measuring technology adoption. It also elaborates on how these models can be used and improved by other new studies. Gaps were identified and analytical techniques and methodologies used in these articles were reviewed to inform future studies. The review serves as a basis for the designing of a conceptual framework that shows how adoption and food security concepts are interrelated. The literature therefore gives evidence of previous studies and the gaps thereof.

2.3 Review methodology

Peer-reviewed journals and book chapters on CSA between 2010 and 2023 were reviewed. The year 2010 was considered because it was the time when the term CSA was coined by the Food and Agricultural Organization of the United Nations (FAO). Other findings of literature reviews focus on how impact and adoption have been empirically measured by other researchers. The extraction of review articles was made from reputable and indexed electronic databases such as Science Direct, Springer, Taylor and Francis, Sustainability, and Hindawi. Key search words and terms

used were climate change, CSA adoption, food security, welfare, impacts, Sub-Saharan Africa, and Ethiopia.

2.4 Review findings

The review findings are presented based on the following: i) the concept of CSA and its role in addressing climate change impacts; ii) CSA technologies promoted in Ethiopia (impacts and adoption patterns), and iii) A discussion on how impact and adoption have been measured and analyzed by other researchers.

2.4.1 Definition of climate-smart agriculture

By reorienting agriculture with a view to better integrate climate responsiveness and agricultural development, CSA is an integrated approach to landscape management such as cropland, livestock, fisheries, and forests aiming at achieving sustainable and increased productivity, building adaptive capacity to climate change effects (household resilience), and reduce emissions. Poverty eradication, ending hunger, and taking swift actions to combat climate change and its impacts were the three major targets of sustainable development goals aspired to be achieved in 2030 by the global community. The key determinant of whether these objectives can be met lie on agriculture and the way it is going to be managed in the years leading up to 2030. Agriculture has been, and will further be used as a key instrument in exterminating poverty, hunger, and all forms of malnutrition.

The CSA is an approach to agricultural transformation that aims to address the intertwined challenges of climate change and food security (Lipper et al., 2018; Steenwerth et al., 2014). It is a set of agricultural practices designed at increasing productivity, improving and building resilience (adaptation) to different shocks, and mitigation of climate change impacts. The CSA thus has three interlinked pillars i.e. sustainably improving agricultural production (productivity), enhancing resilience (adaptation), and reducing greenhouse emissions (mitigation). The nature of climate-smartness of a certain CSA technology is thus based on the impact it has on these three key pillars. Interventions ranging from climate services information to field management have the potential to achieve these objectives (Van Wijk et al., 2020). These interventions of CSA can deliver two or more climate-smart benefits. For instance, practicing agroforestry in a farm can improve farmers' adaptation to climate change and reduce emissions through carbon sequestration (mitigation). Likewise, drought-tolerant improved crop varieties can increase productivity in times

of drought while at the same time enhance the adaptive capacity of farming households. It must therefore be understood that there is no one-size-fit-all solution of CSA. The implementation of CSA becomes more effective when it extends beyond the level of farm plot and is applied in an integrated manner that considers sectoral priorities, cumulative combined effect of CSA technologies, and transformational change potential. To speed-up the transition to CSA, smallholder adoption of farming technologies is crucial. While CSA is diverse in nature, studies revealed that just about five technology clusters i.e. water management, crop tolerance to stress, conservation agriculture, intercropping, and organic fertilizer account for almost 50% of all CSA technologies identified by professionals as climate-smart across 33 nations all over the world covering climate-smart profiles (Khatri-Chhetri et al., 2019). The adoption of CSA, despite its potential benefits, is still generally low, particularly in Sub-Saharan Africa (SSA). For instance, the adoption of minimum tillage in Malawi, maize-legume rotations in Tanzania and soil and water conservation (soil bunds and ridges) in both Tanzania and Kenya is by far less than 10% of all farmers (Ariom et al., 2022).

Though the ambitious policy framework built largely on the Climate Resilient Green Economy (CRGE) strategy and an enabling institutional infrastructure, Ethiopia has taken major steps towards mainstreaming climate change into agricultural planning. The same authors reported that there exist variations in the level of adoption of CSA practices across various crops of Ethiopia. For instance, maize, tef, wheat and barley CSA practices adoption ranges from 30-60% in mid lands and highlands of Ethiopia (Feed the Future, 2017)

2.4.2 CSA technologies in a mixed farming system

In SSA, smallholder farming systems are characterized by low agricultural productivity, which is attributed to generally poor farming management systems that are typified by low input application, insufficient weed control, diseases, pests, and inadequate labor (Sheahan & Barrett, 2017), and lack of adaptive mechanisms against the shocking effects of climate change-induced extreme temperature and rainfall stress (Bjornlund et al., 2020). The effects of climate change are therefore worsening the already resource-constrained smallholder farmers' situation, with more extreme weather events and erratic weather patterns reducing the already low agricultural productivity (Abegunde et al., 2022b; Giller et al., 2021). Smallholder farmers' agriculture is confronted with a range of climate risks to the degree of posing far-reaching consequences on

sustainable food systems. Uncertain and rapid rainfall patterns increase smallholders' vulnerability, threatening food production, and aggravate rural poverty (Giller et al., 2021). Annual precipitation in Ethiopia is projected to decline by 10.8% to 13.1% under 2.4°C to 3.34°C warming scenario, a condition that could lead to a higher risk of drought (Orkodjo et al., 2022). These scenarios of projected climate change lead towards limited diversification options for smallholder farmers as a result of limited carrying capacity of crop and livestock productivity. On the other hand, agriculture is known to be one of the principal contributor to climate change, accounting 24% of global GHG emission through nitrous oxide (N₂O) from manure and synthetic fertilizer, carbon dioxide (CO₂) emitted from soil organic carbon decomposition, and methane (CH₄) from enteric fermentation (Laborde et al., 2021; Vetter et al., 2017). Given the desire to maximize agriculture output for food security, emissions from agriculture in Africa are projected to rise rapidly.

Ethiopia has an agricultural-based economy with the sector contributing about 32.5% each year to the GDP. Agriculture also provide 80% of employments and 85% of export (National Bank of Ethiopia, 2022; Neglo et al., 2021). Ethiopia's agriculture sector is categorized into four key sub-sectors namely; large-scale commercial farms, small-scale commercial farms, communal and resettlement areas. Smallholder farmers account more than 90% of the cultivated area and output. Ethiopia has not been spared by climate change. The country is experiencing fewer and hotter cold days and the average annual surface temperature has increased by about 1.65°C from 1955 to 2015 (Abebe, 2017). The amount and timing of rainfall received are increasingly becoming uncertain and since 1955, there has been a declining in total amount of rainfall or heavy rainfall and recurrent occurrence of drought. The length and frequency and length of dry spells during the rainy season have risen while the rain days frequency has reduced and this has affected productivity negatively.

There are many interventions appropriate especially to Ethiopian context, which have a great potential to maximize agricultural productivity and climate change resilience while concurrently reducing greenhouse gas emissions from agriculture. Broadly, smallholder farmers are understood as the driving power for rural transformation and poverty reduction in Ethiopia thus, climate change mainstreaming into the country's economic and agricultural development agenda must be a fundamental priority. CSA has been identified as a noble approach to addressing the challenges of food security under the new realities of climate change (Abegunde et al., 2022b). Development

organizations and research institutions have been promoting fodder production and conservation agriculture as the dimension of CSA which improves synergies and trade-offs among food security, adaptation capacity, and mitigation as a basis for practical reorientation and evidence for agricultural policy response to climate change. It is anticipated that by implementing climate-smart agricultural technologies, climate change risks and threats to agriculture can be minimized by improving the adaptive capacity of smallholder farmers through building resilience and resource use efficiency and maximizing the mitigation potential of the agricultural landscape. Therefore, this study seeks to examine the relevance of CSA technologies as climate resilient strategies towards the attainment of food security in mixed farming systems of Geshy watershed, Southwest Ethiopia. It will also estimate the optimum mix of these technologies that maximize gross returns among farmers.

CSA promotes best practices of agriculture such as conservation agriculture, integrated soil fertility management, precise/balanced fertilizer management and use of improved varieties in addition to boosting the use of all available and applicable solutions of climate change in impact focused and pragmatic manner. The approach ensures agroecosystem management for sustainable and improved productivity, improved food security and increased household income while at the same time enhancing and preserving the environment and the resource bases (Akamani, 2021). Table 1 presents a range of CSA practices in smallholder farming system of Geshy watershed. Most of these can apply to similar agroecological zones of the country and beyond. These practices improve productivity and address food security, but their ability to address the adaptation and mitigation pillars vary with the farmer and agro-ecological zones and regions.

2.4.3 CSA in Ethiopia context

In Ethiopia in general and in the study area in particular, the key CSA technologies promoted among the vast listings include soil and water conservation, drought and disease tolerant improved crop varieties, improved forage & fodder production, small-scale irrigation, agroforestry practices, use of organic fertilizer (manure, compost & vermicomposting), crop rotation with pulses, crop planting/sowing following crop calendar and integrated soil fertility management (Habtewold, 2021). These CSA technologies were promoted by international research organizations, governments, Universities and Non-Governmental Organizations (NGOs). Though CSA

technologies address household food security, their potential to address adaptation and mitigation dimensions to climate change varies (Zougmore et al., 2018).

2.4.3.1 Drought and disease resistant improved crop varieties

One of the key outputs of agricultural research are generation of improved crop varieties and making sure that they improve agricultural productivity and food security. Farming communities may adapt to climate change impact through drought and heat tolerant crops adoption that are better suited a drier and warmer climate and have the capacity to offset climate change induced yield losses. These varieties of crops are critical for managing current climatic variability and to a developmental climate change.

The Ethiopian Institute of Agricultural Research (EIAR) and the National Maize Program of Ethiopia in collaboration with the International Maize and Wheat Improvement Center (CIMMYT) has been releasing improved breeds of drought-tolerant maize and wheat working with seed marketing companies. Other collaborations with The Consultative Group for International Agricultural Research (CGIAR) centers such as International Center for Tropical Agriculture (CIAT) have also been involved in legume breeding like beans that tolerate drought and meet smallholder farmers demands. The Integrated Seed Sector Development of Ethiopia (ISSD) has also promoted small grains of high yielding varieties such as sorghum, *teff*, wheat and barley varieties. These varieties have been supported by agronomic interventions like integrated soil fertility management practices including conservation agriculture , which is known to be one of the CSA technology.

In Ethiopia, the Drought Tolerant Maize for Africa (DMTA) project which was launched in 2006 by CIMMYT, International Institute of Tropical Agriculture (IITA) , and the national research institute developed drought-tolerant (DT) hybrids of maize and open-pollinated varieties (Simtowe et al., 2019). A DT maize variety increased grain yield by 15% and reduces crop failure by 30% (Simtowe et al., 2019). The variety therefore offers some insurances over dry spells and mid-season droughts. A study by Fisher et al. (2015) indicated that a switch to DT maize seeds in Eastern Africa give and extra income of US\$240/ha or more than eight months of food at no extra cost. Again, another study in West Africa showed that improved maize varieties increased household food security (Amole et al., 2022). Yet, other findings found out that additional one

hectare of land under improved maize varieties improved annual food expenditure per capita levels by over R4,000 (Fisher et al., 2015).

2.4.3.2 Conservation agriculture

The practice of conservation agriculture (CA) is based on three agricultural practices promoted as a strategy for intensifying sustainable agriculture that include mulching with crop residue, minimum tillage, and crop rotation (Gameda et al., 2022). Conservation agriculture increases crop yields through improved infiltration of water, soil fertility improvement, and moisture conservation (when mulch is applied). Reduced tillage and precision in fertilization application can save farmer's labor and other costs. To capitalize the benefits of CA, complementary practices are needed i.e. stress-tolerant varieties improvement to overcome biotic and abiotic stresses, appropriate nutrient management strategies to improve biomass and productivity, careful pest control mechanisms using chemicals, weed and disease pressure, planting and machinery efficiency improvement to reduce labor, groundcover improvement with alternative organic resources or diversification with agroforestry and green manure, provide farm power and facilitate timely planting for seeding, and favorable policy environment for promoting the technology (Thierfelder et al., 2018). Despite these benefits, rate of adoption have been low. Empirical evidence on CA performance including climate smart characteristics have largely relied on agronomic data from on the station trials, thereby missing potential effects of real behavior of farmers. Some studies that employ observational data usually fail to account for selection bias or fully control for potential sources of all endogeneity (Hill et al., 2021; Li et al., 2021). CA was introduced to Ethiopia with its full components in 1998 by SG-2000 and was demonstrated on 77 farmers' plots on maize in Central Ethiopia. The technology demonstration reached more than 16 districts in 2008 and to 35 districts recently (Abera et al., 2020). The Sustainable Intensification of Maize-Legume Cropping System for Food Security in Eastern and Southern Africa (SIMLESA) project has been working with over 100,000 farming households to enable them practice CA based practices (Abera et al., 2020). Currently, the public agricultural extension system has taken up CA projects and programs researches and demonstration initiatives. Among the number of NGOs promoting CA in Ethiopia, Migbare Senay Children and Family support organization in Amhara, The Canadian Food Grains Bank working with Food for Hunger Ethiopia in Beneshangul-Gumuz, and Terepeza Development Association in Wolita are recently supporting CA promotion in various parts of the country (Mango et al., 2017).

Table 1: Common CSA technologies for smallholder farmers

CSA category	Components	Benefits	Selected references
Conservation agriculture	Reduced tillage Crop residue management Crop rotation/intercropping with cereals and legumes	Carbon sequestration Reduce emissions Resistance to dry and hot spells Enhance soil fertility	(Khatri-Chhetri et al., 2017; The Global Green Growth Institute, 2021)
Crop management	Drought-resistant varieties Intercropping with legumes Bio-fortified crop varieties Improved storage and processing techniques Crop diversification Crop rotation Sowing date adjustments Use of cover crops	Improved soil fertility Improved yield Increased food security Increased household incomes	(The Global Green Growth Institute, 2021; Eshete et al., 2020)
Agroforestry practices	Home/kitchen gardens Woodlots Improved fallows and rotation fallows Trees dispersed on croplands Boundary planting, shelterbelts and live fences Hedgerow planting	Improve crop productivity Contribute climate change mitigation Improve household income Improve soil fertility	(Khatri-Chhetri et al., 2017; The Eshete et al., 2020)
Soil, water and nutrient management	Contour ploughing Cereal-legume intercropping Water storage structures (e.g. water pans) Planting pits Terraces and bunds, vetiver grass Infield water harvesting technologies (e.g. tied ridges, potholing, tied contours, infiltration pits, dead level contours) Improved irrigation Mulching Pits, dams, ridges	Reduce soil erosion Soil fertility improvement Increased water use efficiency Increased infiltration Increased yield	(Khatri-Chhetri et al., 2017; The Global Green Growth Institute, 2021; Eshete et al., 2020)
Improved Livestock management	Integrated manure management Improved livestock health Feed improvement (e.g. feed treatment) Forage and rangeland management Animal breeding Genetic improvement and conservation Animal husbandry improvement	Improved livestock health Improved market off-take rates Improved livestock productivity Improved household income GHG reduction	(The Global Green Growth Institute, 2021; Eshete et al., 2020)
GHG emission reducing technologies	Climate-smart forestry Integrated pest management Afforestation Solar energy Improved energy efficient cooking technologies Biogas	Reduced GHG emission Reduced deforestation Improve household income	(Khatri-Chhetri et al., 2017; The Global Green Growth Institute, 2021; Eshete et al., 2020)
Knowledge related	Seasonal climate forecasts Soil management with remote sensing Digital credit to access CSA technologies Extension advisory based on weather	Improved financial inclusion Improved knowledge Reduced transaction costs	(The Global Green Growth Institute, 2020)

2.4.3.3 Agroforestry and fodder production

In a mixed farming system, farmers benefit from livestock production through draught power for ploughing, manure from dung for soil fertility improvement, meat, investment, milk, and income (selling milk, meat, and hiring out ploughing animals). One of the major constraints of productivity of livestock for smallholder farmers is the low quality and quantity feed that rely on natural pastures. Due to climate change effects, the grazing area has continued to dwindle. Especially, during the dry winter season when they subsist on poor quality roughage such as grasses and crop residues, cattle perform less in their productivity. Disease incidence, low milk production of cows, poor drought performance, and low body condition score can be culminated by shortage of feed as a result.

In the last decade, new CSA technologies like agroforestry and fodder production have been promoted and emerged to improve smallholder farmers' livestock production system in the face of climate change. Tree fodder banks can enrich livestock diets with protein supplements and thereby increase productivity (Rojas-Downing et al., 2017). Most frequently, fodder trees are grown in hedges along contours or field boundaries to reduce soil erosion and *Calliandra calothyrsus* is an example. Some of the known fast growing trees which are commonly planted and tolerant to frequent droughts and pruning are *Albizia chinensis*, *Celtis australis*, *Acacia catechu*, *Bauhinia variegata*, *Ficus roxburghii*, *Leucaena leucocephala*, *Grewia optiva*, *Morus serrata*, *Melia composite*, and *Olea glandulifera* (Derero & Kitaw, 2018). The International Center for Research in Agroforestry (ICRAF) in Ethiopia has spearheaded a variety of agroforestry technologies adoption. This include the rich indigenous agroforestry practices in Ethiopia, particularly in the Southern and Western Ethiopia where the major source of staple food such as enset (*Enset ventricosum*) is obtained. The International Livestock Research Institute (ILRI) has also been involved in providing trainings on homemade fodder production system for both beef and dairy cattle (Lelamo, 2021). Various studies have evaluated adoption of fodder from different agro-ecological zones using logit modelling to identify the adoption drivers and even gross margin analysis for profitability determination. Research findings conducted on small scale farmers that are growing fodder for their dairy cattle supplement revealed that landholding size, dairy herd size, agro-ecological zones and membership of the dairy association are the key factors determining fodder bank adoption of farmers (Saylor et al., 2018). The significance of fodder supplementation of livestock include increased stover and grain yield and increased milk yields when the

technology is applied to crop enterprises. One study conducted in the Philippines revealed that during the dry season, fodder trees were the most important feed source that increased the net income from livestock production from US\$70 to US\$505 per household (Wiebe et al., 2022). Additional benefits of fodder shrubs include the provision products like bee forage, firewood, stakes, and seeds that are sold sometimes and services like soil fertility management, fencing, control of soil erosion, and animal health and reproduction improvement. Depending on the location, fodder trees can help to minimize soil erosion and runoff. The trees are resistant to drought, deep rooted and maintain high protein levels during scarce high quality feed and dry seasons. They also enhance productivity of livestock, which helps reduce emission of methane per unit of output and also reduce carbon emissions as commercially manufactured concentrates substitutes. Fodder crops such as Lablab and *Mucuna pruriens* are fixing nitrogen and help improve soil fertility. When used in home legume-based formulated diets, they also contribute to improve productivity. Across the number of literatures reviewed and to the best of the author's knowledge no studies was conducted on the adoption effect of CSA livestock technologies on household food security in Ethiopia.

2.4.3.4 Climate-smart pest management

Climate-smart pest management (CSPM) describes the use of integrated pest management with interdisciplinary strategies and approaches (Heeb et al., 2019). It includes provision of information and tools to farmers such that they can put into action proactively prevention measures (e.g. crop diversification or measures that reduce pest attack susceptibility). Instances of pest prevention approaches include control of pests using biological, chemical, cultural and mechanical techniques, building farm resilience through e.g. pest scouting to monitor available and newly emerging pests, and pull-push technologies. Pest control however remains to be a challenge and it is among the various constraints responsible for lower yields. The International Center for Insect Physiology and Ecology (ICIPE) along with other partners developed a 'push-pull' climate-smart approach based on other companion cropping that controls pests effectively in cereals (sorghum, maize, and millets) including the parasitic weed Stem borer and Striga. This, thus, demands an efficient and early warning system in the country.

2.4.3.5 Climate-smart bio-fortified crops

There has been micro-nutrient rich and high yielding drought tolerant crop varieties expansion recently through genetic bio-fortification with vitamins and minerals to ensure nutrition security even in the existence of climate change (Barasa et al., 2021). Harvest Plus, a worldwide consortium co-led by CIAT and the International Food Policy Research Institute (IFPRI) has promoted and released seven, bio-fortified crops in 13 countries (Garg et al., 2018). In Ethiopia, CIAT has organized the promotion of Pro-Vitamin A maize, Orange Fleshed Sweet Potato (OFSP), Quality Protein Maize (QPM), and iron and zinc-enriched beans. To date, the bean varieties released in Ethiopia include the Mexican 142, Awash 1, Awash Melka, Awash 2, Batu, SAB-736, and Nazreth (Amare & Kassahun, 2021).

All the CSA technologies discussed contribute to food security and household income and eventually improve livelihoods in different ways. CSA adoption improved nutrition (calorie intake and protein) and increased dietary diversity where the benefits are more pronounced when households adopt multiple CSA technologies other than in isolation (Teklewold et al., 2019).

2.4.4 Econometric models and theories

Adoption is the process of decision making in which individuals learn about an innovation first and must decide to either adopt or reject it (Neil, 2012). The adoption behavior of farmers' have been justified by researchers using four paradigms namely the adopter's perception model, the economic constraint model, the planned behavior model, and the innovation-diffusion models.

2.4.4.1 Adopter perception model

The model suggests that the adoption behavior of farmers is conditioned by the perceived attributes of the technologies. Even with full information, thus, farmers may evaluate subjectively any technology given. Perception of farmers are subjective but also directly influencing the decision for CSA adoption. A study in Zimbabwe found out that future climate change perceptions affected the decision for drought-tolerant maize varieties adoption. Likewise, the perception of Striga highly affected climate-smart pull technology adoption. It is hence crucial to take into account perceptions even in econometric modelling. It is also relevant because researchers have come up with evidences that new technologies affect men and women differently as they experience economic, social, and environmental reality differently (Murage et al., 2015). In mixed farming system, men and women play different roles and thus their contribution to agriculture become

different. Literature indicated that women invest over 90% of agricultural labor in addition to reproductive roles. Effective adoption and dissemination of CSA technologies can be ensured where there is full knowledge of how the technologies are perceived by the adopter.

2.4.4.2 Economic constraint model

Economic constraint model depicts that smallholder farmers make choices on all activities during production e.g. whether or not to use purchased inputs, which crop to grow, which crop to grow on which field, which crop to grow on what field size, etc. The objectives and goals and the constraints of resources of the individual farming household determined the decision making. The model assumes that the household act as a unified unit of production and consumption with the aim of maximizing utility subject to its production function, total time constraint, and household income (Kraaijvanger et al., 2016). However, this is not the case in real-life situations as members of households do not possess same functions of utility and thus the study enquired households to identify decision-makers for activities as well as identifying who decides to adopt certain agricultural technologies. The model indicates that in the short run, input fixity like access to land, credit, and labor limits flexibility of production and thus conditions the adoption of technologies. It highlights adoption behavior is determined by the factors that affect profitability with asymmetrical resource endowment distribution.

2.4.1.3 Planned behavior model

The theory of planned behavior predicts individuals intentions to follow a certain behavior based on the assumption that people behavior is regulated by behavioral intentions which are governed by the attitudes, subjective norms, and perceived behavioral control of individuals (Atta-Aidoo et al., 2022) (Fig. 3). The farmers' behavior intention can again be defined as that motivation of farmers regarding their plan of conscious decision to put effort to implement a certain behavior (Atta-Aidoo et al., 2022; Dessart et al, 2019). Behavior intention indicates the best predictor and immediate antecedent of performing an actual behavior. Stronger behavior intention towards a behavior, by implication, shows a stronger likelihood of that behavior performance (Begheri et al., 2019). Such behavioral intentions can precisely be estimated from the attitude of farmers towards that specific behavior, subjective norm, and perceived behavior control (Atta-Aidoo et al., 2022; Despotovic et al., 2019).

Attitude refers to the favorable or unfavorable evaluation of behavior. The overall examination of behavior and belief in its desired outputs influence the attitude towards a behavior (Despotovic et al., 2019). This implies a positive attitude towards a behavior leads to a better intention of performing that behavior. Various studies (Atta-Aidoo et al.,2022; Dessart et al, 2019; Razaeei et al., 2018) have showed the role of attitude in farmers’ intention prediction to adopt farm practices. Attitude can be considered as a significant determinant of an individual’s behavior and intention (Razaeei et al., 2018).

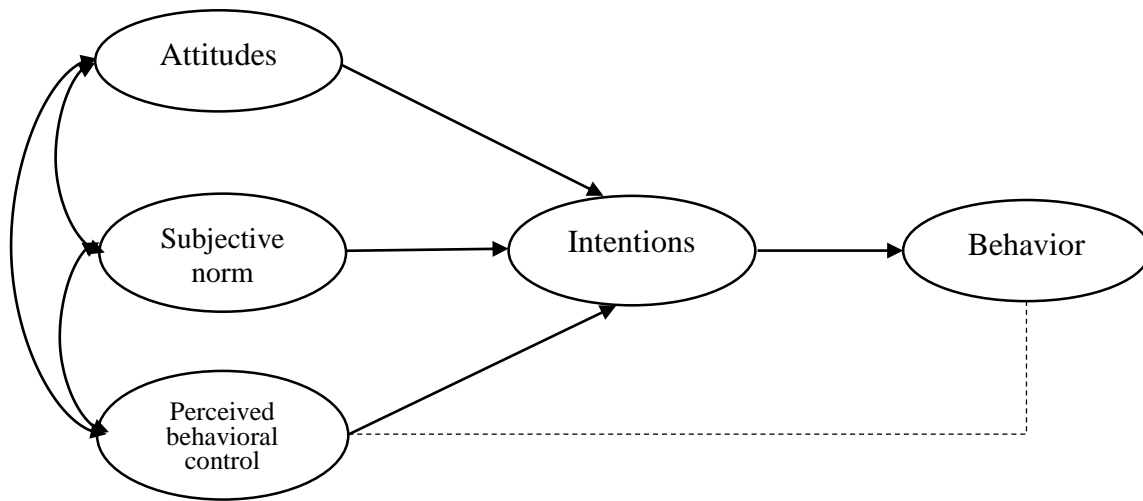


Figure 3: Planned behavior model
Source: (Ajzen,1991)

Subjective norm indicates social influence perceived from internal and/or external sources to perform or not perform a certain behavior. Such pressure may emerge from internal sources such as members and relatives of a family or external sources including personnel and friends from government agency or an NGO (Begheri et al., 2019). Approval of the perceived behavior by important people within a society also serves as a source of pressure that induces personal intention of carrying out that particular behavior. Therefore, subjective norm measures the effect of the community on farmer’s decision making processes. Perceived behavior has been considered as the most important influencing factor of farmer’s intention for new agricultural practices adoption (Dessart et al., 2019).

Perceived behavior control is associated to the perceived ease or difficulty in performing a certain behavior. Perceived behavior control is concerned with the existence of control factors that may hinder or promote the performance of a certain behavior (Atta-Aidoo et al., 2022). These control

factors could be in the form of skills, money, time as well as cooperation with others (Dessart et al., 2019) and these may influence the ability of farmers to perform a particular behavior. The engagement of a farmer in a given behavior is subject to the belief of the farmer in the likelihood of having access to the required opportunities and resources. Perceived behavior control is an important predictor of farmers' intention to adopt farm practices (Atta-Aidoo et al., 2022; Despotovic et al., 2019; Dessart et al., 2019). Perceived behavior control directly influences intention and sometimes affect behavior (Razaei et al., 2018).

Though a plethora of studies show that the adoption behavior of farmers is highly influenced by economic incentives, the theory of planned behavior proven valuable in justifying farmers decision making processes (Begheri et al., 2019). This is because farmers are not solely profit-maximizing bodies (Razaei et al., 2018), but can be influenced by motivations of other individual and intrinsic attributes especially when the decision could have both environmental and social consequences (Atta-Aidoo et al., 2022; Despotovic et al., 2019).

2.4.1.4 Innovation diffusion model

Innovation diffusion model indicates that the dissemination of technology consist of four components namely the innovation-decision process, the rate of adoption, the perceived attribute of the technology, and individual innovativeness (Miranda et al., 2016). The process of innovation decision process is characterized by five stages i.e. knowledge, persuasion, decision making, implementation, and confirmation. The first stage dictates the exposure of farmers to packages of CSA technologies. The farmer gets lessons on how the technology operates and the potential benefit it provides to farmers. The model assumes that while the technology is culturally and technically suitable, high search costs and information asymmetry may restrict its adoption and as such, it is vital for farmers to get all the necessary information on the technology. Development organizations and research have thus used different approaches to ensure that farmers get access to CSA information. A range of methods from governmental extension services use, innovation platforms, use of local non-governmental organizations, and lead farmers are suggested in the model. In adoption analysis, it is hence vital to get to know the frequency of contact between the farmer and extension personnel. Mass media (newspaper, television and radio) and interpersonal communication can also be sources of information to the farmer. The decision whether to use or not to use the technology comes after the farmer is persuaded first. Then, the farmers proceed to

judge a certain technology using five attributes i.e. compatibility, relative advantage, complexity, observability, and friability. Farmers thus can consider the advantages and disadvantages of the technology. Relative advantages is usually expressed in terms of social, economic or other benefits, referring to the extent to which an innovation is perceived as better than the traditional practice it replaces. Compatibility justifies the degree to which a potential adopter perceives an innovation which is to be consistent with their existing practices or values. Compatibility with what is already available makes the new technology seem more certain, easy to adopt and more familiar. On the other hand, the degree to which innovations are considered difficult to use and understand is referred as complexity. Low adoption rate can be resulted if potential adopters perceive innovation is complex. Observability is the degree to which the innovation result is visible to others, and finally friability refers to the degree to which an innovation may require limited experimentation. The technology will then gradually be spread among people and over time resulting in various categories of adopters based on the adoption rate. The category of adoption depends on the availability of information on the technology.

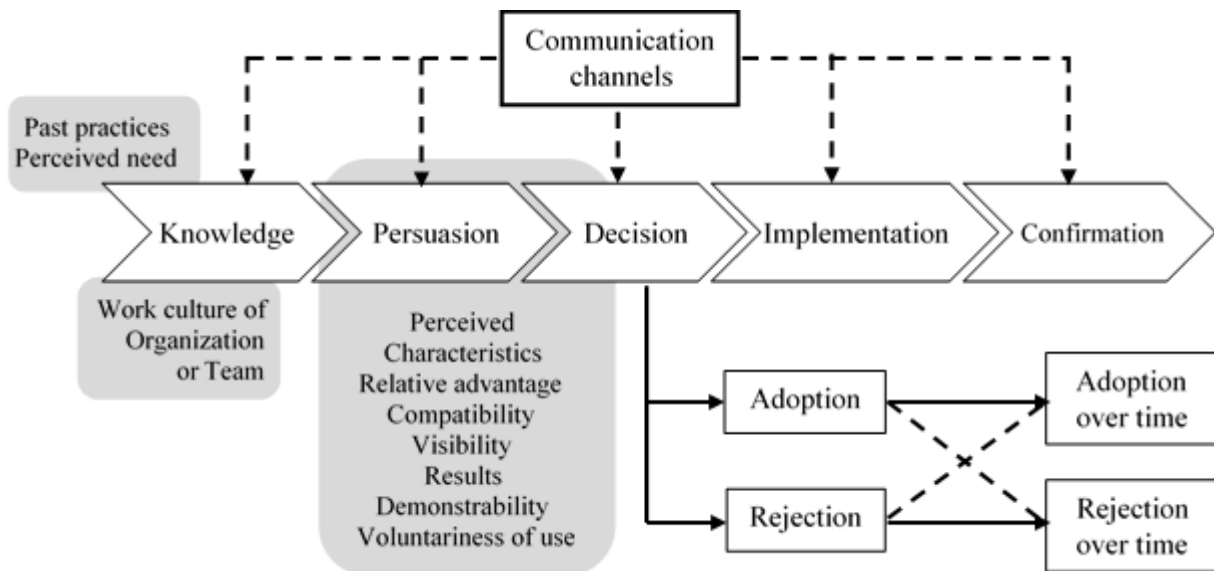


Figure 4: Technology diffusion model
 (Source: Rogers (2003) as cited by Miranda et al., (2016))

Rogers categorized the adopters into five classifications namely innovators, early adopters, early majority, late majority, and laggards. Individuals who are venturesome are innovators that are eager to try new perspectives and risk takers (Fig. 1). Early adopters are often local opinion leaders in the system who work as role models and they need to see the value of innovation quickly. The

early majority make decisions after they are convinced of the benefits and is form the largest majority. Skeptical and cautious individuals that do not adopt till the large majority has done so constitute the late majority. Relatively, they are often poor and risk averse. Laggards are the last group of adopters. They are suspicious of change agents and innovations. They seldom take risks and are usually poor. Information on adoption patterns in important as it can serve as feedback to policy makers and technology developers. Some farmers, for instance, adopt and dis-adopt over the years, while some are non-adopters. Several limitations encounters the innovation diffusion model. The assumption that information and the willingness of the individual to change as important variable is one of the shortcomings. An individual is characterized based on his behavior without considering factors influencing his behavior. In fact, many other conditions are known to affect agricultural innovation adoption. These include the level of resource endowments of individuals, farmer's objectives, availability of support systems, access to resources, and land can constrain CSA technology adoption to small number of individuals in farming communities. This could work for female-headed households whose productive resources are restricted in some people compared to their male counterparts. In such cases, an innovative individual can be regarded as a laggard, while land or labor resources that could be associated with the technology can cause non-adoption or late adoption. The extension system information and support services may also restrict innovation dissemination by targeting innovators and early adopters while disregarding the others.

2.4.5 Econometric data for impact and adoption analysis

In adoption studies, researchers have used cross-sectional data, time-series data, and panel data. In measuring the aggregate measure of adoption time series data has been used e.g. the proportion of farmers using technology each time. Adoption is therefore captured as a logistic shaped function (Aweke et al., 2021). However, this approach is limited as it does not provide the adoption intensity and does not say a lot about the underlying dynamic processes. Cross-sectional studies take one time snapshot of farmer's use of technology at some date. The limitation in cross-sectional studies is that the technology may be defused through the population incompletely. Unless a recall data is included in the data collection instrument, the process of adoption itself is less understood. The collection of data at certain points for same farmers is panel study. Household change effects can be allowed to be investigated. Panel data integrates intra-individual and inter-individual diversity dynamics which have advantages of model parameters for accurate inference, make computation

simpler, and easy statistical inference as well as having greater potential of capturing the complexity of human behavior over time (Ioan et al., 2020).

2.4.5.1 The double hurdle model

The double hurdle model assumes that farm communities are faced with double hurdles in the process of agricultural decision making. Farmers decide to adopt primarily and then consequently decide on the amount of production under the chosen CSA technology. Various factors affect these two stages. The double hurdle model is ideal because it allow distinctions between determinants of production involvement using CSA technologies and the level of participation through the two distinct stages. In the first stage. The model involves running a Probit regression model to evaluate factors influencing the decision to adopt CSA technologies. The second stage follows the use of truncated regression model on the participating farmers to analyze the level of adoption. The double hurdle model allows a data subset to pile up some value without causing bias in estimating the determinants of the continuous dependent variable in the second stage (Kassa et al., 2021) and thus all data for participants is obtained in the remaining sample.

2.4.5.2 Single and multiple equation model

In analyzing decisions of adoption, econometric literature emphasizes the use of both single and multiple equation models. Three models have been often used to analyze adoption of technology namely logistic function (logit), linear probability, and normal density function (Probit) models (Taherdoost, 2018). A binary choice variable as a dependent variable is used by these models. The logistic regression is a mathematical-statistic approach that is used when the dependent variable is dichotomous (takes only two values). The occurrence or non-occurrence of an event is predicted by logistic regression. The application of binary choice variable as a dependent variable however may not capture the intensity of adoption. To overcome this problem, a Tobit estimation approach can be applied to analyze the intensity of adoption where the dependent variable is continuous with zero limit. However, the Tobit model is statistically limiting as it assumes that similar factors influence both the probability of non-zero adoption and level of intensity (Simtowe et al., 2016). Tobit, Probit, and Logit are all instances of single equation models. These models, despite the appropriateness of a single equation model, have limitations. Technology adoption is usually incremental that gives rise to various level of adoption. The rate and level of adoption also change over time with understanding new knowledge and as such the more appropriate model become multi equation model. An instance is a research in Madagascar that employed a dynamic Probit

model to isolate factors associated with dis-adoption (Wordofa et al., 2021). The double hurdle model and structural equation models (SEM) are examples multiple equation models. The SEM is a flexible and comprehensive multivariate statistical model that computes relationships between observable and latent variables. The model integrates factor analysis, regression analysis, among others.

2.4.6 Factors affecting adoption of CSA technologies

Multifaceted reasons are presented behind farmers; adoption of CSA and lessons can be drawn from previous research findings on farmers' reluctance in agricultural technology adoption. Various studies have examined several endogenous (attitude towards risk, human capital, access to financial capital, etc.) and exogenous (location, institutional, rainfall patterns, soil quality, market infrastructure, farming system, etc.) factors that affect adoption of technologies. Four major classifications can be identified that includes socio-economic factors, socio-demographic characteristics, farmers' perceptions, and institutional factors (Ruzzante et al., 2021). Factors influencing risk could be observable and unobservable such as ambiguity and attitudes towards risk. Varied preferences of individuals for uncertainty may reflect the patterns of technology adoption. Individuals utility functions or their value functions are therefore affected by such preferences, which in turn may result in otherwise production decisions and/or sub-optimal investment. It is hence relevant to study unobservable factors, along with observable ones when studying the adoption of technology.

2.4.6.1 *Socio-demographic characteristics of farmers*

Socio-demographic characteristics of farmers include gender, age, education, and household of the household head. Age of the household head has been found to have both positive and negative influences on adoption by various researchers. A research conducted in Vietnam found both positive and negative associations between age and adoption of CSA technologies in production of rice across multiple provinces. In one province Bac Lieu and Thai Binh provinces, the younger farmers were more likely to adopt CSA technologies while in Ha province, older farmers were more likely to adopt CSA technologies (Laksono et al., 2022). Older farmers have the likelihood of CSA technology adoption because they have better access to credit especially for technologies that require some investment or have accumulated capital. Older farmers also learn from experiences on how they cope with shocks of climate change and variability and thus can better

identify new technologies based on experiences compared to younger farmers. However, in some areas, age can be limiting to technology adoption as an aged farmer has reduced physical ability (Yap et al., 2022). This shows that younger farmers are more risk takers than the older ones. Farmers that are risk-averse will wait for longer for technology adoption. The level of education of household head has a positive impact on new technology adoption. The justification given is that a better educated head of household is expected to more likely to get new technologies and understand than uneducated ones in a shorter period. Also, level of education is considered to increase the ability of farmers, use and process information pertinent to adoption.

Household head gender also play a role in technology adoption and mixed evidence have been reported by researchers. Some empirical studies reveal a greater rate of technology adoption among male-headed households, compared to female headed ones because of discrimination i.e. access to external inputs, information, and services is less than men (Gebre et al., 2019; Neway & Zegeye, 2022; Hirpa Tufa et al., 2022). Men in male-headed households in most societies are the one that makes control over productive resources such as labor, land and capital that are key in new technology adoption and as a result adoption is positively influenced. Female-headed households, in comparison, have limited adoption because of the different access to productive resources (labor, land, capital) as well as access to extension and training services. Higher access to information and resources thus gives such technology the possibility to adopt.

Size of household is linked to availability of labor and will influence decision of adoption based on the labor the technology requires (e.g. ox-based cultivation). Adoption of technology usually needs more inputs of labor and adoption is positively influenced if this requirement is fulfilled by family farmers. However, with scarce labor, there is more likelihood to have low-adoption or non-adoption of labor-intensive technologies for families. Different research findings found a positive relationship between the adoption of labor-intensive CSA technologies and household size such as intercropping and row marking (Gikonyo et al., 2022; Wossen et al., 2019).

2.4.6.2 Institutional factors

Services that include insurance, finance, information belonging and dissemination to a group of society are regarded as institutional factors. Adoption of technology often goes along with input use such as pesticides and fertilizers, among others. Access to credit enables the farmer to purchase various necessary inputs thereby influencing technology adoption positively. Different access to

credit can produce differential technology adoption. Few researchers have found out that credit access promotes risky technologies adoption through relaxation of the liquidity limitation and promoting the risk-bearing ability of households. Households with better access to credit can abandon inefficient income diversification strategies and take up riskier but efficient alternatives. Access to credit can decrease constraint of income on farmers, enabling them buy vital inputs as well as labor hiring. The positive impact is realized when credit is invested agricultural practices rather than used for social affairs (Girma, 2022). Low rate of adoption have however been reported in nations where there is discriminations by credit institutions to female-headed households, and as such they are unable to finance yield improving technologies.

Information acquisition about new technologies is yet another factor that influence technology adoption. It helps farmers to gain knowledge on effective use of technology, thereby speeding-up its adoption. Extension services access has a positive influence on adoption of technology due to the awareness created by the extension agent about its potential and innovation. Extension services can play a crucial role in innovation diffusion and implementation and bridge the gap between farmers and the new technology. Extension services link researchers (innovators) and farmers (technology users) through information dissemination to farmers on the benefit and effective use of the new technology. The dissemination of information by the extension worker can counterbalance the negative impact of lack of formal education by farmers on the overall decision and adoption of some technologies (Mohammed & Abdulai, 2022). Information access through extension helps farmers make informed decisions as minimizes the uncertainty about the performance of a technology and thus may change the assessment of an individual. Dissemination of information must be reliable, accurate and consistent, otherwise, it can hinder adoption.

Social group membership promotes social capital enabling trust, information and ideas exchange about new technologies. Farmers that take part in community-based groups are likely to engage in social learning about the technology hence enhancing their likelihood of technology adoption. Social groups however may also have negative influences on adoption of technology, particularly where free-riding behavior exists. Some studies propose an inverted U-shaped curve of individual adoption, implying that there is positive network effects at low adoption rates but negative at high adoption rates (Manda et al., 2020). As more individuals engage in experimentation of new technologies, others join and free-ride on experimentation of others.

2.4.6.3 Farmers perception of the technology

The adopter's perception on the benefits and associated cost of production play a key role in adoption consistent with the neoclassical conventional model view that a rational economic individual maximizes his utility. Farmers interests deviate towards the short term benefits than the long term. Perceptions of farmers on technologies may give a better understanding of adoption of technology since farmers deal with technologies and probably perceive technologies differently from extension agents and researchers. The knowledge, and information about the innovation and the socio-economic situation of farmers determine their perception of innovation. The level of information is based on the farmer's level of training and education that they receive about the technology. A study in Ethiopian highlands found out that perception on soil and water and soil conservation technologies was positively influenced by access to training and education (Moges & Taye, 2017). Studies also showed that the perceived benefits of CSA in terms of contribution towards income and productivity influenced adoption positively (Musafiri et al., 2022; Shahbaz et al., 2022). Farmers who also consider the technology to be consistent with their demands and compatible with their biophysical environment are more likely to adopt it as they find it as a positive investment. Farmers perception of CSA technology performance thus can significantly impact the decision of adopting them. User's judgement of the technology value and judgment factors like efficiency of the technology and utility determine adoption. Farmers' preference for a certain technology is affected by their evaluation of yield and overall benefit gained over a year. Technologies demanding few assets, have lower premium risk and are less expensive, have relatively higher probability of being adopted. However, on the other hand, technologies that need new skills are costly and time-consuming to learn, may experience slow adoption. Thus the level of participation is based on the economic return of the technologies to other options.

2.4.6.4 Socio-economic factors

Socio-economic factors like household income, farm size, asset ownership, and livestock have positive and negative impact on adoption. Some research findings, however, showed a negative impact of farm size on adoption. Small size of farm may give an incentive to adopt input-intensive innovations like land-saving or labor-intensive technology. Farmers' with a small parcel of land are likely to adopt land-saving technologies such as zero-grazing and greenhouse technologies among others as an option to increased agricultural production (Tatis Diaz et al., 2022). An inverse relationship between cultivable land size has been found for few technologies e.g. crop

diversification where yield is improved by intensification of crop diversification through improved soil fertility and moisture conservation (Teklewold et al., 2019). However, land size can have positive influence on technology adoption especially for scale-dependent technologies that require more land. Larger landholder households can choose to try new technologies compared to those with smaller size of land. On the other hand, technology adoption can be positively affected by asset ownership. Studies revealed that farmers with more asset ownership were likely to have equipment, money, and materials required for new technologies (Zeng et al., 2018). The income necessary for accessing inputs related with new technologies can be generated by assets. Non-agricultural income enables farmers to meet capital costs related with new technology and minimize the risk of experimenting on new technologies. Instead of examining factors influencing adoption alone, it is appropriate and ideal for studies to further look at factors influencing the intensity of use of these technologies. This is detrimental for value chain stakeholders as it enables them propose better strategies for scaling up adoption in mixed smallholder farming communities to enhance productivity and subsequent food security. Table 2 provides a summary of some researches on impact and adoption. It provides an analytical model used and the results in terms of significant factors influencing the impact and adoption.

The variations in the characteristics discussed (farmer and farm characteristics, institutional factors etc.) show that CSA technologies scaling out cannot be a one-size-fits-all model. CSA technologies must be tailor-made to satisfy the diversity found in farming communities. A research finding by Mwongera et al. (2017) using Principal Component and clustering revealed that typologies affected adoption. Farmers with no formal education, poor farmers, and inexperienced farmers were low adopters compared to the wealthier, experienced, and well-resourced counterparts.

Table 2: A summary of some key impact and adoption studies

Details examined	Analytical model and sample size	Significant factors/results	Source references
Determinants of adoption of CSA among farmers in Bale Echo-region, Ethiopia	404 households interviewed Multi variate Probit Model	Age, education, land size, total asset, Frequency of extension contact, farmers awareness of climate change	(Negera et al., 2022)
Adoption of CSA practices through women involvement in decision making processes: exploring the role of empowerment and innovativeness	384 farmers interviewed Multivariate Probit model and Propensity Score Matching	Land size, credit access, use of farm machinery	(Shahbaz et al., 2022)
CSA in African countries: a review of strategies and impacts on smallholder farmers	164 published articles on strategies and impacts analyzed	Agricultural practices, degraded area restoration practices, forest and cropland regeneration practices, livestock production practices	(Ariom et al., 2022)
Impact of CSA on household income and asset accumulation among smallholder farmers in Kenya	312 households interviewed Propensity Score Matching (PSM)	Household income is significantly enhanced by adoption which in turn, improves asset accumulation of households	(Ogada et al., 2020b)
Determinants of CSA small-scale farming households in South Africa	357 farmers interviewed Generalized Ordered Logit Regression Model	Education, farm income, land size, extension services contact, media exposure, group membership, and climate change perception	(Abegunde et al., 2020)
Effect of CSA practices on household food security in smallholder production systems: micro-level evidence from Kenya	384 farmers interviewed Principal Component Analysis (PCA) and Multinomial Endogenous Switching Regression Model	Four packages of CSA; crop management, field management, farm-risk reduction, and soil management practices and gender, farm size, farm assets	(Wekesa et al., 2018a)

2.4.7 Principal component analysis used with cluster analysis

The existence of heterogeneity among farm households caused by variation in resource endowments, location, farming objectives, and constraints faced leads to variation in the level of use and the choice of CSA technologies adopted by farmers. Studies have categorized farms into groups that have common characteristics (household typologies) (Leonardo et al., 2015; Musafiri et al., 2020; Abegunde et al., 2020) and also classified farmers on multiple technology adoption categories (Yigezu et al., 2018) using two multivariate statistical techniques (PCA and Cluster analysis) which are sequentially employed.

Principal Component Analysis (PCA) is a statistical dimension reduction estimation technique that uses an orthogonal transformation to transform a set of correlated observations into a set of variables that are linearly uncorrelated called principal components (Tsoulfidis & Athanasiadis, 2022). PCA evaluates a minimized set of features that represent the original data in a reduced-dimensional subspace with minimal information loss. PCA and other related methods provide a means for data summarization and information extraction about individual variations. It reduces the dimensionality of the data and examine primary patterns.

Among the several assumptions of PCA, linearity between variables, presence of multiple variables, adequate sample size which should exceed 50, (tested by Kaiser-Meyer-Olkin (KMO) test of sample adequacy), fractionally implying that among variables, adequate correlations should exist for data reduction (tested using Bartlett's sphericity), and that the size of outliers must not be significantly large to minimize the heterogeneous influence on the results (Chen et al., 2020). The partial correlations and correlations between variables with a small KMO indicative of high correlated data is compared by KMO. The null hypothesis is checked by Bartlett's test of sphericity non-linear variables used in PCA that the inter-correlation matrix came from a population.

The output of PCA (retained PC's) are then placed to cluster analysis to get the bundles/cluster of technologies. Cluster analysis split a set of observations into clusters or groups such that observations that are put in the same group are more identical to each other than observations put into various clusters (Clayman et al., 2020).

2.4.8 Theoretical framework

This study adopted the theoretical framework of the theory of utility. As described by Terdo and Adekola (2014), the decision on whether or not to adopt any CSA practice lies under the profit and

utility maximization theory. The utility theory focuses on an individual's behavior on the basis that based on individuals' preferences they constantly rank their choices. The important aspect in the theory of utility concerning the choices being made is whether an alternative has a greater utility than another and not the measure of the difference between the available alternatives. The concern of making choices among farmers on which agricultural practice to adopt lies in the idea of ordering available alternatives based on the benefits they provide.

2.4.9 Conceptual framework

This study synthesized a conceptual framework based on literature reviewed on impact and adoption as shown in Figure 2. The simplified Schematic representation indicates climate change effects and dynamics surrounding drivers of adoption, introduction of CSA technologies, and the potential effects. Farmers face low productivity that involved in a mixed farming system, where climate change worsens these effects. Thus, different organizations have introduced CSA technologies as a fix to the problem. To maximize utility (welfare e.g. household food security and income), farmers will adopt various combinations of CSA technologies. The major drivers for adoption of CSA technologies are hypothesized to compare farmer and farm characteristics, market access, technical and institutional advice. The adoption is further hypothesized to exhibit different influences on food security and welfare indicators such as household income and household income security i.e. fertilizer, labor, and some environmental benefits.

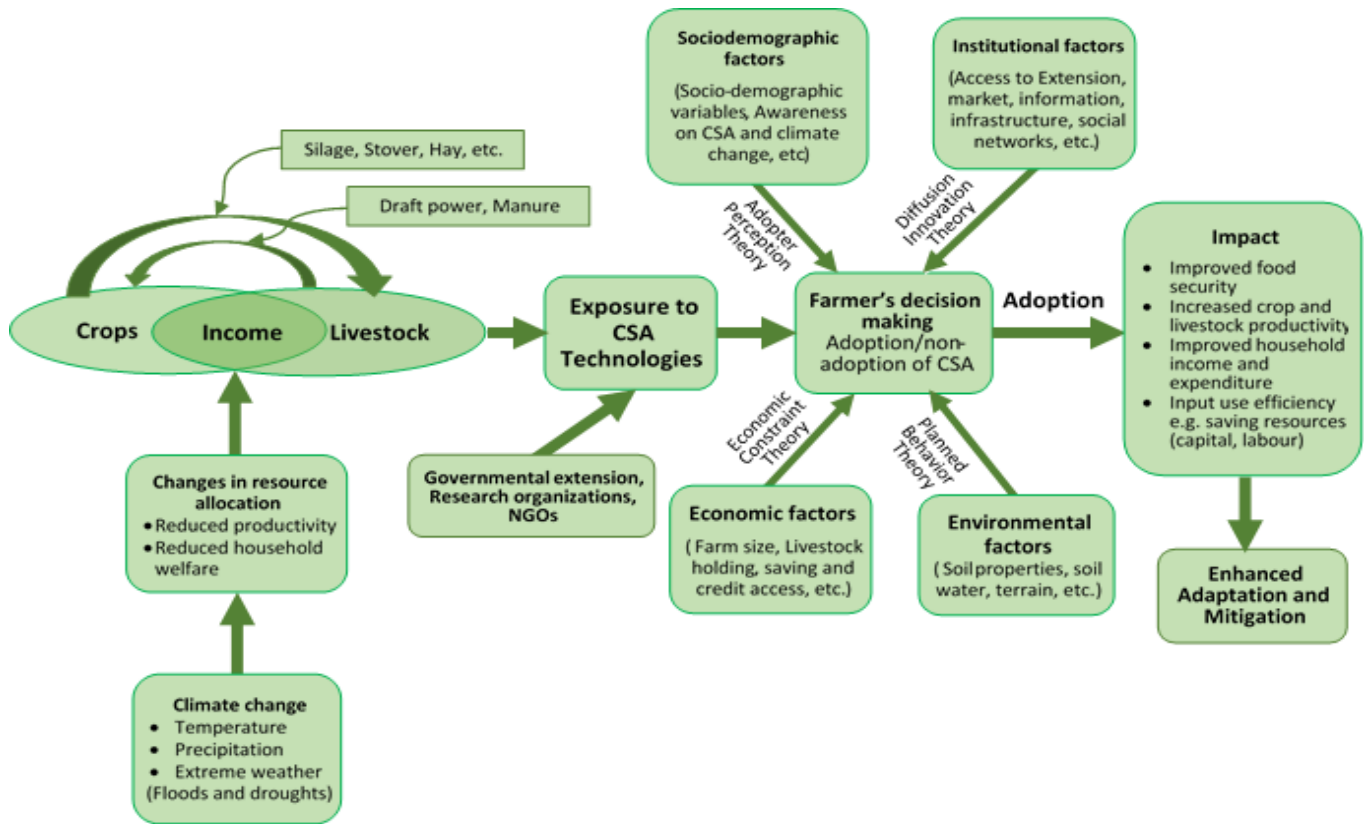


Figure 5: Conceptual framework
(source: own development)

2.5 Conclusion and recommendation

The reviewed literature indicates that climate change influence smallholder rain-fed agriculture through increased temperature and reduced amount of rainfall. Ultimately, these will lead to reduced productivity from heat stress, changing rainfall patterns, as well as increased incidence of diseases and pests. The promotion of different CSA technologies offers solutions to these adverse effects. In addition to drought-tolerant maize varieties, conservation agriculture has emerged as the most popular form of CSA promoted in Ethiopia. Production of fodder for livestock supplementation during the dry season is still very low. Many factors ranging from farmer and farm characteristics, perception among others, access to information are deriving factors affecting adoption and intensity of adoption. Based on perceived and actual benefits, it can be observed that CSA technologies are adopted differently among smallholder farmers. Thus, depending on the needs of different types of farmers, it is wise for development workers scaling out CSA and make tailor-made technologies. The various multiple potential benefits of CSA extends from improved yields, improved food security and incomes to enhanced resilience of communities and increased

environmental benefits. Research and extension agents must share the evidence of these effects with policy makers to promote supporting and buy-in policies for CSA technologies. A widespread impact can therefore be achieved if all actors along the vital farmer value chains are to be involved. However, it should be noted that while Ethiopia stands to benefit from CSA, some research have explored combinations of technologies adopted by farmers as well as modelling optimal combinations for smallholder farming systems. The limited available studies on CSA in Ethiopia focused on individual CSA technologies adoption and impact studies are greatly dependent on farm demonstrations other than real adoption by farmers without help from NGOs. Further, based on the author's knowledge, no study has attempted to model maximizing CSA technology combinations in mixed farming systems.

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CHAPTER 3: SPATIOTEMPORAL VARIABILITY AND TRENDS OF
RAINFALL AND TEMPERATURE: IMPLICATIONS TO CLIMATE-SMART
AGRICULTURE IN GESHY WATERSHED, SOUTHWEST ETHIOPIA

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SPATIOTEMPORAL VARIABILITY AND TRENDS OF RAINFALL AND TEMPERATURE: IMPLICATIONS TO CLIMATE-SMART AGRICULTURE IN GESHY WATERSHED, SOUTHWEST ETHIOPIA

3.1 Abstract

This paper examines the spatio-temporal trends and variability of temperature and rainfall in Geshy Watershed of South Western Ethiopia. The available grid-based daily rainfall and temperature data used in this study for 1986-2020 was collected from Bonga and Shebe meteorological stations, which was accessed from the Ethiopian National Meteorological Agency (NMA), whereas same data for Gewata, Gojeb and Decha was computed using IDW interpolation technique. Spatial variability and temporal trends of temperature and rainfall were analyzed using XLSTAT and ArcGIS 10.8 software. The Mann-Kendall test was used for trend analysis. Variability analysis was also done using the coefficient of variation and precipitation concentration index. The study reveals increasing trends in rainfall; and insignificant and high variability but increasing trends of temperature. The variabilities and trends justify the spatio-temporal differences along different seasons (spring locally known as '*belg*', summer locally known as '*kiremt*', and annual). The watershed is characterized by high to moderate rainfall coefficient of variation, significant years of high concentration of rainfall, and substantial negative annual rainfall anomalies; that severe variability was found in the summer season. These variabilities and trends, especially late onset and early cessation of rainfall and increase in temperature could create favorable conditions for insect and disease proliferation that eventually reduces agricultural productivity. Household income, which is solely based on agricultural production, declines corresponding with the changes which in turn affects household resilience. Maladaptation in the form of deforestation, fuelwood and charcoal selling, agricultural land expansion, and practicing input-intensive agriculture that contributes to greenhouse gas (GHG) emissions are taken as an alternative livelihood strategy. In conclusion, spatiotemporal variabilities and trends of rainfall and temperature affect agricultural productivity, reduced household resilience leading to low adaptive capacity, and increased GHG emissions, which are known to be major pillars of climate-smart agriculture (CSA). In response, area-specific CSA technologies such as small-scale irrigation, improved animal husbandry, efficient inorganic fertilizer use, using manure, crop residue management, using high-yielding improved crop varieties, and using disease-resistant varieties are recommended.

Keywords: Spatiotemporal, Rainfall, Temperature, Variability, Trend, Climate-smart agriculture

3.2 Introduction

Climate change, together with other megatrends such as population growth, food insecurity, rapid urbanization, and water scarcity increases resource competition and heightens tensions and instability (UNFCCC, 2017). Climate change, usually associated with rainfall and temperature variability, is the rapidly unfolding problem of the agrarian society; and has been affecting a wide range of small-scale farmers through environmental and socioeconomic impacts (Ekwueme & Agunwamba, 2021; Dong et al., 2020; Gladys, 2017). The inconsistent trend characterized by complex geographical locations generally results in a tendency of decreasing rainfall and increasing temperature since the mid-twenties century (Nouaceur et al., 2017); and a general increase in rainfall by 0.5-1.0% at mid and high altitudes to decrease at low altitude at a rate of 0.3%, increase in temperature by 0.72 °C with significant spatiotemporal variability (Ofgeha & Abshire, 2021).

Africa is one of the vulnerable continents to climate change due to its high reliance on rain-fed agriculture and low adaptive capacity (Moges & Bhat, 2021). The trends have been towards increasing but inconsistent trends in rainfall and increasing temperature (Suryabhadgavan, 2017; Solomon et al., 2021; Shumetie & Alemayehu Yismaw, 2018). Intense and intermittent characteristics of rainy seasons justified by concentrated wetting in the late rainy season have been a common phenomenon in recent decades (Ofgeha & Abshire, 2021). Spatio-temporal variability in rainfall in the form of dry spells occurrences, seasonal droughts, and episodes of torrential rainfall with flooding and a significant increase in temperature are more frequent in east Africa recently than in the past (Adnew Degefu et al., 2018; Mahmood et al., 2019; Kandji et al., 2006; Laban, 2009).

Ethiopia's traditional agricultural system along with its geographical location and low adaptive capacity left the country vulnerable to climate change effects (Moges & Bhat, 2021). The main causes of livelihood vulnerability and food production deficits in the country have been associated with extreme weather events such as shocks related to drought, temperature rise, and rainfall variabilities and trends. Climate change is coming out as the major challenge to Ethiopian agriculture specifically to the efforts to reduce poverty (Kassie, 2014).

Climate-smart agriculture (CSA) approach, which was first proposed by the Food and Agricultural Organization (FAO), is one of the best measures to deal with the adverse effects of climate change and reduce smallholder farmers' vulnerability to it. The approach was designed to integrate three

fundamental objectives; 1) insure food security through sustainable agricultural productivity, 2) enhance adaptive capacity through increased resilience, and 3) reduce agricultural greenhouse gas (GHG) emissions (Gladys, 2017).

Various studies confirmed that the adoption of CSA practices in Ethiopia is limited to a few practices such as soil and water conservation practices, improved animal husbandry, organic manure use, use of improved forages, multiple cropping, and water management activities (Mekonen & Berlie, 2020). These practices though not implemented on a big scale at the household level, climate change, land fragmentation, and land tenure issues are highly deteriorating the performance of agriculture to fulfill the objectives of CSA (Mekonen & Berlie, 2020).

Smallholder farmers of the study area introduced with CSA technologies and are deciding to adopt these new CSA technologies that can withstand climate change impacts, such as small-scale irrigation, using disease and insect-resistant improved crop varieties, using high-yielding improved varieties, and agroforestry practices. The aim of this study is, however, to assess the trends and variabilities of rainfall and temperature both in space and time, and to examine its potential implication on CSA in the Geshy watershed of South Western Ethiopia.

3.3 Materials and methods

3.3.1 Research design and data collection technique

Types and sources of data

Grid-based monthly and daily temperature and rainfall data for trend and variability analysis have been obtained from the National Meteorological Agency of Ethiopia (NMA) for the year 1986-2020. The gridded data are data series reconstructed based on gauge station records. The gridded dataset is important in view of the fact that there are very limited weather stations that have sometimes missing data values. Bonga meteorological station being the only gauge station serving the watershed, other four meteorological stations (Gewata, Gojeb, Decha, and Shebe) surrounding the watershed were used as data sources. The additional four-gauge stations were subjected to the Inverse Distance Weighted (IDW) interpolation technique to find representative values. Missing case weather values were managed by taking the average of preceding and succeeding months and days (for missed monthly and daily data) but excludes years of missed data. In addition, a survey of 384 households was conducted using simple random sampling technique by employing semi-structured questionnaire to understand the trends in crop yield against weather variabilities. This

was further triangulated by conducting 15 key informant interviews of agricultural experts and 8 focus group discussions of community elders.

3.3.2 Data analysis technique

In reviewing the literature, a number of techniques have been developed for rainfall and temperature analysis that generally fall into trend and variability analysis categories. Trend analysis usually uses both parametric and non-parametric tests for reliable data. In parametric tests, missed data and outliers can adversely affect normality and homogeneity of variance throughout the series of data. A non-parametric test was preferred over the parametric in that the former is more suitable for censored, non-normally distributed, outlier, and missing data, which are occurring frequently in time series hydrological series data. And hence, a non-parametric Mann-Kendall (MK) test was used in this study to identify trends of meteorological variables, which is supported by studies conducted by Bayable et al., (2021); Alemayehu et al., (2020); and Asfaw et al., (2018) that state MK test is a widely used non-parametric test that examines time series trends without indicating whether the data is linear or non-linear. Variability analysis uses the coefficient of variation (CV), and Precipitation concentration index (PCI).

MK test is well known non-parametric test commonly used to detect a series of climatic data, environmental data, or hydrological data trends. MK tests show monotonic trends (increasing or decreasing) and provide statistical outputs on whether the trend is statistically significant or not. There can have chances of obtaining outliers in the dataset and adopting the non-parametric MK test is relevant because rather than looking at the random variable value, the statistic is based on the (+ or -) signs that make it less affected by outliers (Habte et al., 2021). Trend analysis was performed on annual basis as *kiremt* and *belg* seasons. These seasons were treated separately for trend analysis as they exhibit the onset of rainy seasons. This helps us understand the cessation and onset seasons. The pettitt test, which is a non-parametric test used to detect abrupt changes in the average value distribution of the value of interest, was used to check homogeneity as described by Kamal & Pachauri (2018). Every value was compared to its subsequent. If the value of the later time is greater than the value of the previous time, the statistic S is incremented by 1. Whereas, if the value from a later time is smaller than the previous sampled data value, there will have a decrement of S by 1. Such decrement and increments of net results provide the final value of S.

The MK test statistic ‘S’ is determined based on Kamal & Pachauri (2018) and Neha (2015) using the formula expressed in Equation (2):

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^n \text{sgn}(X_j - X_i) \quad (2)$$

The use of trend analysis is performed to a series of time X_i that is designated from $i = 1, 2, 3, \dots, n-1$ and X_j , which is designated from $j = i+1, 2, \dots, n$. every data point X_i is considered as a reference point that is equated with the remaining data points X_j as presented in Equation (3):

$$\text{Sgn}(X_j - X_i) = \begin{cases} +1 & \text{if } (X_j - X_i) > 0 \\ 0 & \text{if } (X_j - X_i) = 0 \\ -1 & \text{if } (X_j - X_i) < 0 \end{cases} \quad (3)$$

Where X_i and X_j represent annual values in years i and j ($j > i$) respectively.

In observation of more than 10 ($n \geq 10$) the ‘S’ statistic is usually assumed as approximately normally distributed with the $E(S)$ and mean becoming 0 as explained by (Asfaw, 2016). The variance statistic, in this case, is then given Equation (4):

$$\text{Var}(S) = \frac{n(n-1)(2n+5) - \sum_{t=1}^m t1(t1-1)(2t1+5)}{18} \quad (4)$$

Where n is the number of observations and t the sample time series ties. Equation (5) shows the Z_c test statistic is as follows:

$$Z = \begin{cases} \frac{S-1}{\sigma} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sigma} & \text{if } S < 0 \end{cases} \quad (5)$$

Where Z_c exhibits normal distribution, a positive Z_c and a negative Z_c show an upward and downward trend for the respective periods. Sen’s test for Slope estimation determines both the slope (i.e the rate of linear change) and intercept based on Sen’s method. The trend magnitude is predicted by Kamal & Pachauri (2019) and Drapela & Drapelova (2011) methods of slop estimator. A positive β value results in an ‘upward trend’ (increasing values with time), while a negative β value results in a ‘downward trend. Now, the slope (T_i) of all pairs of data is equated based on Kamal &

Pachauri (2019). Generally, the slope T_i between time series of any two values can be determined using Equation (6):

$$T_i = \frac{X_j - X_i}{J - i} \quad (6)$$

Where X_j and X_i are regarded as data values at time j and i ($j > i$) consistently. The median value of this N of T_i is taken as Sen's estimator of the slope which is calculated as $Q_{\text{med}} = [T_{N/2} + T_{(N+2)/2}]$ if N appears to be even and $Q_{\text{med}} = T_{(N+1)/2}$ if N appears odd. A positive Q_i value shows an increasing trend or upward and a negative Q_i value indicates decreasing trends or downward time series.

Variability of rainfall and temperature have been computed using CV and Precipitation Concentration Index (PCI) and the time series changes will be analyzed using descriptive statistics and qualitative analysis. A higher CV value indicates higher variability and vice versa which is determined by Equation (7):

$$CV = \frac{\sigma}{\mu} \times 100 \quad (7)$$

Where CV is the coefficient of variation; σ is the standard deviation and μ represents the mean precipitation. Based on (Alemayehu et al., 2020), a CV value is low ($CV < 20$), moderate ($20 < CV < 30$), and high ($CV > 30$).

The PCI is employed to determine the variability (pattern of heterogeneity) of rainfall at various scales (seasonal or annual). The computation of PCI values follows Valli et al. (2013), as expressed in Equation (8):

$$PCI_{\text{annual}} = \frac{\sum_{i=1}^{12} p^2 i}{(\sum_{i=1}^{12} P_i)^2} \times 100 \quad (8)$$

Where P_i is the amount of rainfall of the i^{th} month.

PCI values lower than 10 show uniform rainfall distribution (low concentration of precipitation), values between 11 and 15 indicate moderate concentration, values between 16 and 20 represent high concentration or irregular rainfall distribution, and values above 20 denote very high precipitation concentration as described by Habte et al. (2021).

3.4 Results and discussion

3.4.1 Temporal variability and trends of rainfall and temperature

Temporal variability of rainfall

As shown in Table 3, the average long-term annual rainfall of the study area was 1762.6 mm with a standard deviation of 277 and a coefficient of variation of 0.16%. The lowest (1239.4 mm) and the highest (2349.8 mm) mean annual rainfall was recorded in 1994 and 2019, respectively. Kiremt season (June-September) contributed about 49.1% of the total amount of rainfall, while Belg season (February-May) contributed 34.2% of the annual total rainfall. A study conducted by Mekonen & Berlie (2020) came up with similar results that the summer and winter seasons contributed 68% and 23% of rainfall respectively. Similarly, summer and winter were found to be the highest rainfall seasons, which is supported by a study conducted by Alhamsry et al. (2020). Several more studies by Asfaw et al. (2018);

Table 3: Basic statistics and MK trend analysis of rainfall in the Geshy watershed (1986 – 2020)

Months	Min	Max	Mean	%	SD	CV	MK test	Sen's slope
Jan	0	138.7	46.2	2.6	37	0.80	-1.90 ⁺	-1.111
Feb	4.6	134.6	48.2	2.7	32.5	0.67	-1.22	-0.624
Mar	35.8	184.4	111.6	6.3	36.7	0.33	0.09	0.100
Apr	0	311.1	179.6	10.2	62.6	0.35	1.51	1.647
May	47.7	356.8	217.6	12.3	67.2	0.31	2.24*	2.538
June	82.8	352.1	209.4	11.9	60.2	0.29	2.27*	2.354
July	116.8	462.9	230.5	13.1	81.4	0.35	2.58**	3.050
Aug	121.2	433.4	212.4	12.1	70.4	0.33	0.31	0.215
Sept	118.1	421.5	213.7	12.1	78.4	0.37	2.33*	3.332
Oct	26.8	314.7	161.9	9.2	86.0	0.53	1.63	2.620
Nov	6.4	248.2	82.6	4.7	60.3	0.73	2.58**	2.300
Dec	0	151.8	49.0	2.8	44.0	0.90	-2.29*	-1.455
Belg (FMAM)	336.6	854.6	603.2	34.2	133.2	0.22	1.22	2.779
Kiremt (JJAS)	563.2	1562.7	886.0	49.1	211.8	0.24	2.98**	8.342
Annual	1239.4	2349.8	1762.6	100	277.0	0.16	3.41***	15.750

** is statistically significant at $P < 0.05$

Habte et al. (2021); Dagnachew et al. (2020) all over Ethiopia substantiated the fact that the summer season contributes the highest total rainfall amount while a relatively lower amount is recorded in the winter season.

The results of the Coefficient of variation (CV) indicate that the Kiremt season (June - September) and Belg season (February – May) showed very similar CV of 24% and 22%, respectively. Several studies conducted by Asfaw et al. (2018); Ofgeha & Abshire (2021); Habte et al. (2021) documented similar results that the CV of the summer season was higher and more variable than

the winter season. The annual PCI in the period between 1986 and 2020 is greatly characterized by moderate rainfall distributions (91%) (Table 4). The annual precipitation concentration showed moderate rainfall distribution (91%) while uniform rainfall distribution/low concentration (5.7%) and irregular concentration (2.8%) was also recorded. Belg and Kiremt seasons belong to a very high irregular concentration of rainfall (100 %) of the year. Studies conducted by Alemayehu et al. (2020) reported similar results that very high precipitation concentration was observed in the winter season.

Table 4: Annual, kiremt and belg Precipitation Concentration Index (PCI) for 1986-2020

PCI (%)	Index	Description	Observation years (%)		
			Annual	Kiremt	Belg
< 10		Uniform rainfall distribution/low concentration	5.7	-	-
10-15		Moderate rainfall distribution	91	-	-
16-20		High concentration/irregular rainfall distribution	2.8	-	-
>20		Very high concentration/irregular rainfall distribution	-	100	100

Trends of rainfall

As presented in Table 3, the MK test result showed a statistically significant increasing trend in rainfall for June, July, September, and November. The result also revealed that annual and *belg* rainfall indicated a significant increasing trend. Belay et al. (2021); Mekonen & Berlie (2020); Bayable et al. (2021) reported significantly increasing trends of rainfall in *kiremt* seasons. The regression coefficient also revealed increasing trends at a rate of 15.4 mm/year, 9.8 mm/year, and 2.4 mm/year for annual, *kiremt*, and *belg* rainfall respectively (Fig. 5).

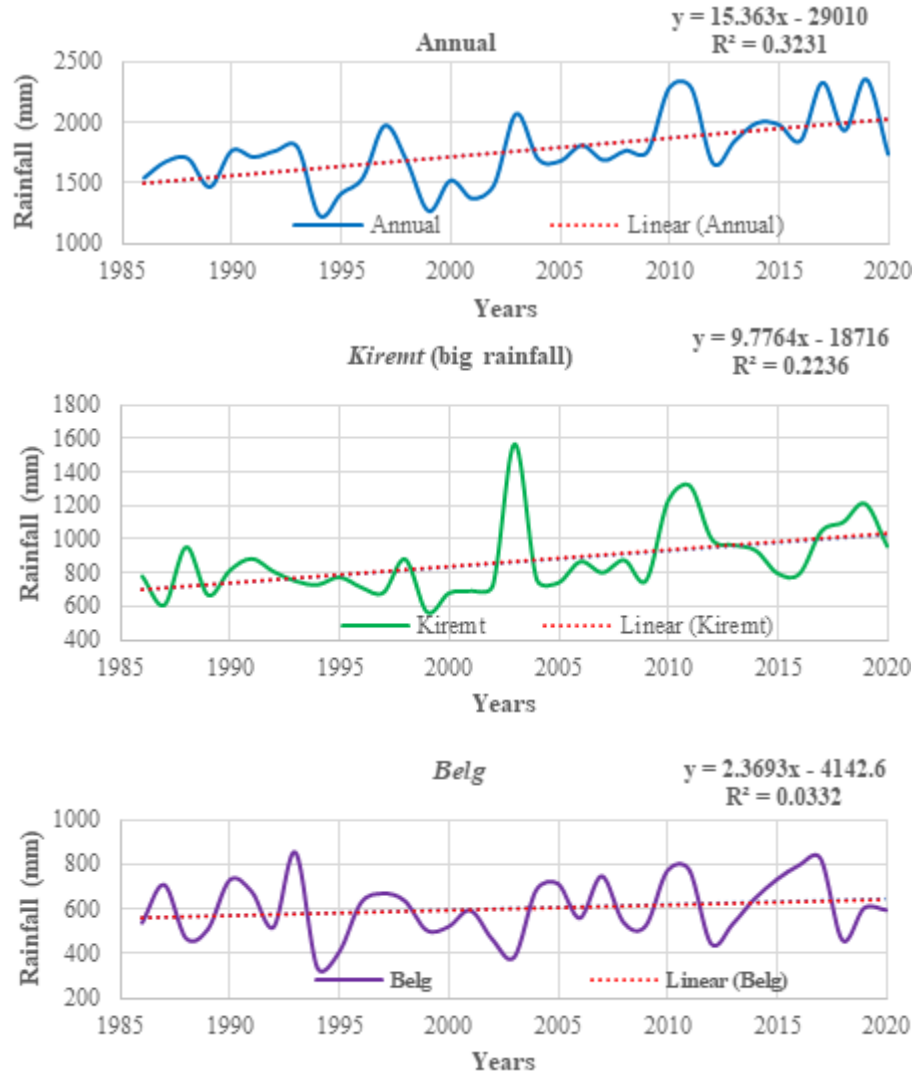


Figure 6: Annual, kiremt, and belg rainfall trends

3.4.2 Temporal variability and trends in temperature

The average monthly minimum, maximum and annual temperature data for the period 1986-2020 were presented to determine the temporal variabilities and trends (Table 5 and Fig. 4). The minimum temperature of the study area was 10.4°C with a maximum of 28.8°C, and an annual average of 19.7°C (Table 5).

Table 5: Monthly and annual MK trend test of temperature (1986-2020)

Month	Tminimum				Tmaximum				Tmean			
	Mean-Tmin	ZMK	P value	Slope	Mean-Tmax	ZMK	P value	Slope	Mean	ZMK	P value	Slope
Jan	10.4	0.20	0.076	0.005	28.4	2.50	0.087*	0.048	19.4	2.02	0.059*	0.029
Feb	11.2	0.94	0.060	0.019	28.8	2.73	0.111**	0.068	20.0	2.78	0.067**	0.040
Mar	12.3	-0.06	0.028	-0.001	28.8	2.41	0.087*	0.048	20.5	1.53	0.042	0.017
Apr	12.9	-0.37	0.042	-0.006	27.9	1.42	0.071	0.038	20.4	0.87	0.032	0.013
May	13.1	-0.26	0.037	-0.005	27.0	0.03	0.040	0.002	20.0	-0.23	0.029	-0.003
Jun	12.7	-0.80	0.028	-0.013	26.5	0.40	0.034	0.005	19.6	0.11	0.031	0.002
Jul	12.8	0.23	0.056	0.007	25.1	-0.94	0.019	-0.016	18.9	-0.72	0.018	-0.010
Aug	12.6	-0.64	0.027	-0.014	25.2	0.24	0.050	0.006	18.9	-0.74	0.024	-0.019
Sep	12.5	-0.17	0.037	-0.003	26.1	1.15	0.053	0.019	19.3	0.62	0.033	0.008
Oct	12.2	0.81	0.048	0.011	27.3	1.65	0.042	0.021	19.7	1.32	0.033	0.012
Nov	11.4	0.68	0.070	0.021	28.0	1.59	0.055	0.029	19.7	0.62	0.040	0.010
Dec	10.7	0.31	0.088	0.005	28.2	2.26	0.073*	0.045	19.5	1.11	0.055	0.022
Average	12.1	0.68	0.040	0.006	27.3	1.16	0.036	0.013	19.7	0.97	0.026	0.008

The regression coefficient for the maximum, minimum, and average temperature indicated an increasing trend at a similar rate of 0.08°C (Fig. 6). Apparently, an abrupt increase in temperature was observed in 2007. At this point, the rate of increase of maximum temperature was found to be faster than the minimum. Accordingly, the rate of maximum, minimum, and annual average temperature increased similarly by 0.8°C. These results were supported by Asfaw et al. (2018); Bayable et al. (2021); Alemayehu et al. (2020); Habte et al. (2021). The authors concluded that increasing trends in maximum, minimum, and annual temperature were found in various parts of Ethiopia within this study period.

The Mann-Kendall result showed that the average monthly maximum temperature revealed a significant increasing trend in December, January, February, and March. However, a non-significant increasing trend in monthly maximum temperature was observed for all the remaining months (Table 5). The overall significantly increasing trend of average monthly temperature was observed to be attributed the increasing trend in maximum temperature (Table 5).

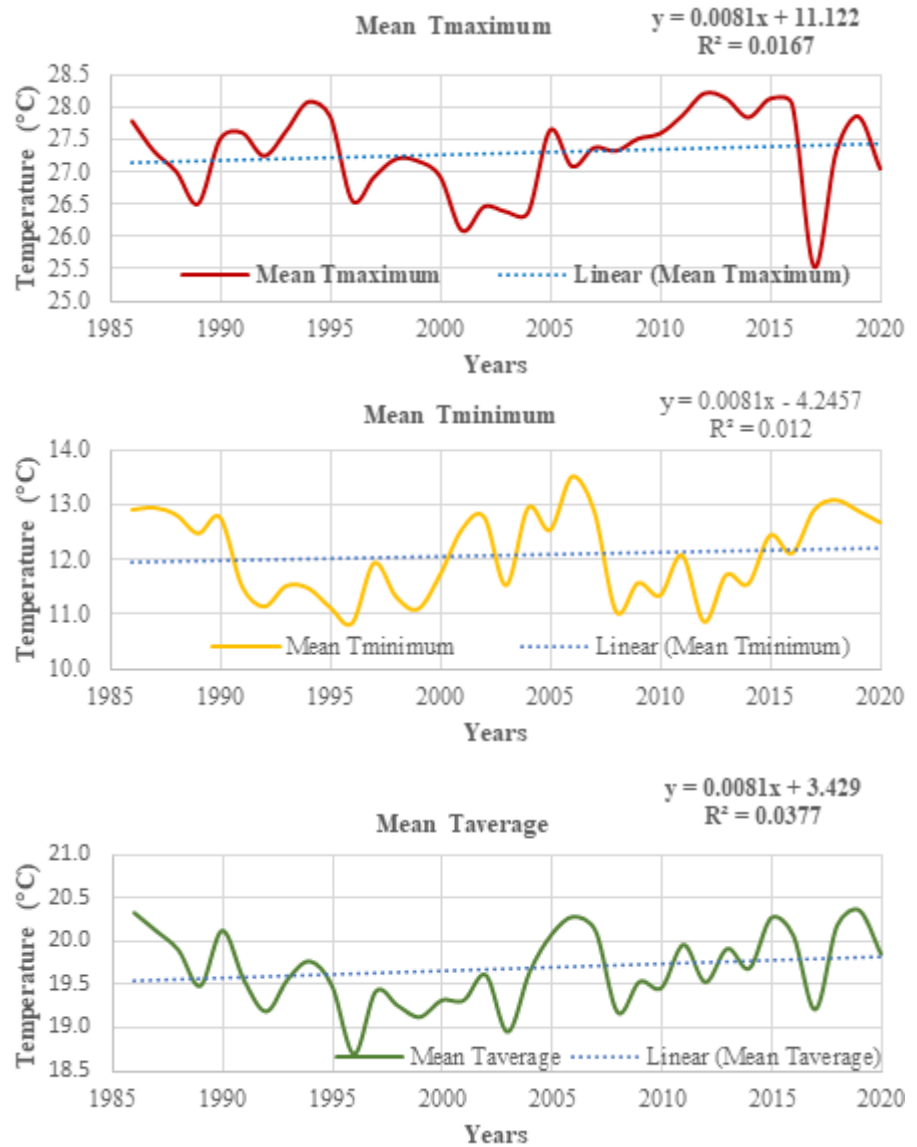


Figure 7: Temporal trends of annual, total, maximum, and minimum temperature (1986-2020)

3.4.3 Spatial variability and trends of rainfall

The long-term spatial trend and variability of mean annual, *kiremt*, and *belg* rainfalls were presented (Table 6 and Fig. 5). The mean annual long-term spatial distribution of rainfall ranges from 1742 mm in station Gojeb to 2261 mm in station Bonga. Four gauge stations (Gewata, Bonga, Decha, and Shebe) receive rainfall between 1939 mm and 2261 mm per year. The remaining station (Gojeb) receives a mean annual rainfall of less than 1742 mm. All these stations are data points surrounding the study area (Geshy watershed) generated by IDW interpolation technique for the purpose of spatial data analysis. The variability of spatial rainfall distribution also exists within a season. For example, the variability of *kiremt* rainfall ranges from 675mm in Gojeb to

1075mm in Bonga, while the rainfall in the *belg* season varies from 663mm in Gojeb to 764mm in Bonga and Shebe. The average annual spatial coefficient of variation revealed that Bonga (CV = 24.5 %) was lower than Gojeb (CV = 27.3 %). The coefficient of variation in *kiremt* and *belg* seasons showed a similar trend to the average annual in which Bonga (CV = 27.9 %) was lower than Shebe (CV = 38.9 %) during *kiremt* and Decha and Shebe (CV= 27 %) was lower than Gewata (CV = 33 %). The PCI revealed a very high concentration in all stations that ranged from (29.8 %) in Gojeb to (30.2 %) in Bonga and Decha. Similar reports were generated by Mekonen & Berlie (2020); Habte et al. (2021); Ofgeha & Abshire (2021); Wakjira et al. (2021).

Table 6: Gauge stations spatial variability and trends of the mean annual, kiremt and belg season rainfall

Variable	Seasons	Attributes	Gewata	Bonga	Gojeb	Decha	Shebe	
Rainfall	Belg	Mean	700	764	663	765	764	
		%	31.2	29.5	29.9	30.2	31.1	
		CV (%)	33	28.3	28.9	27	27	
	Kiremt	Mean	978	1075	675	845	738	
		%	30.3	29.5	30.5	31.4	30.7	
		CV (%)	28.7	27.9	37.7	34.6	38.9	
	Annual	Total	MK test	-2.02**	-1.16**	-1.82**	-1.85**	-1.85**
			Mean	2005	2261	1742	1939	1939
			PCI	29.6	30.2	29.8	30.2	30.1
		Total	CV (%)	27.1	24.5	27.3	26.6	26.6
			MK test	-2.02**	-1.16**	-1.14**	-1.62**	-1.62**

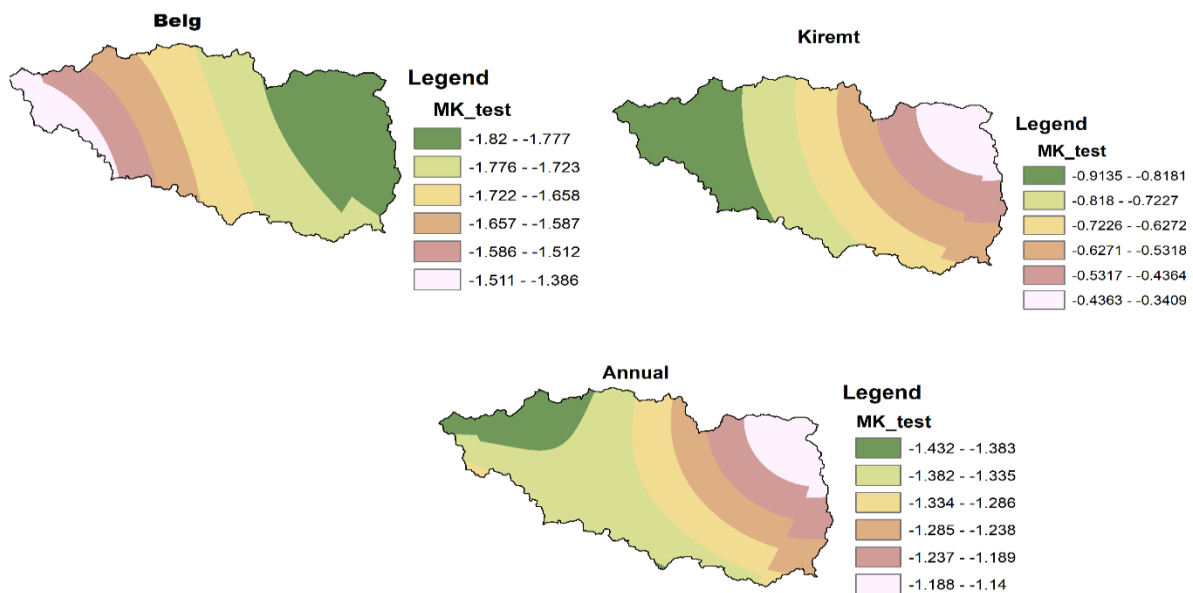


Figure 8: Spatial trends of belg, kiremt and annual rainfall at P<0.05

3.5 Impact of rainfall and temperature variability on climate-smart agriculture

The assessment of the impact of rainfall and temperature variability on maize yield (2010 – 2020) is presented in Figure 7. The identified spatial and temporal variability in rainfall and temperature could trigger a wide-ranging impact on crop production and other agricultural practices of smallholder farmers (Svedberg, 2019). Adequate and timely available rainfall duration and amounts during summer and winter seasons are crucial for agricultural practices (Singh, 2019). Nevertheless, variability and inconsistency of rainfall during winter (Feb-to-May) and summer (June-to-Sept) seasons deteriorates farmers' agricultural practices across their livelihoods. Yet, the delay in the onset of rainfall and its early cessation affected the liftoff farmers for timely and early maturing crops which reduce productivity thereby hampering the food security situation (Robinson et al., 2013). One of the crucial objectives of climate-smart agriculture, ensuring sustainable productivity, is then affected. Similar results were reported by Asfaw et al. (2018); Dereje Ayalew (2012); Kassie (2014) that indicated summer and winter seasons variability in amount and duration in rainfall-induced loss of livestock and crop production leading to chronic food insecurity. Gladys (2017) also described that winter rains could impact long-cycle crop production with crippling consequences for agricultural production. Alemayehu et al. (2020); Moges & Bhat (2021) estimated that a 10% seasonal rainfall variation below the long-term average produced a 4.4% decline in national food production. Similarly, World Bank (2011) further projected that rainfall variability costs 38% of the national growth rate and elevates poverty by 25%. Sanjeevaiah et al. (2021) complimented that the major cause of variation in crop production and the resulting food insecurity is variabilities in rainfall.

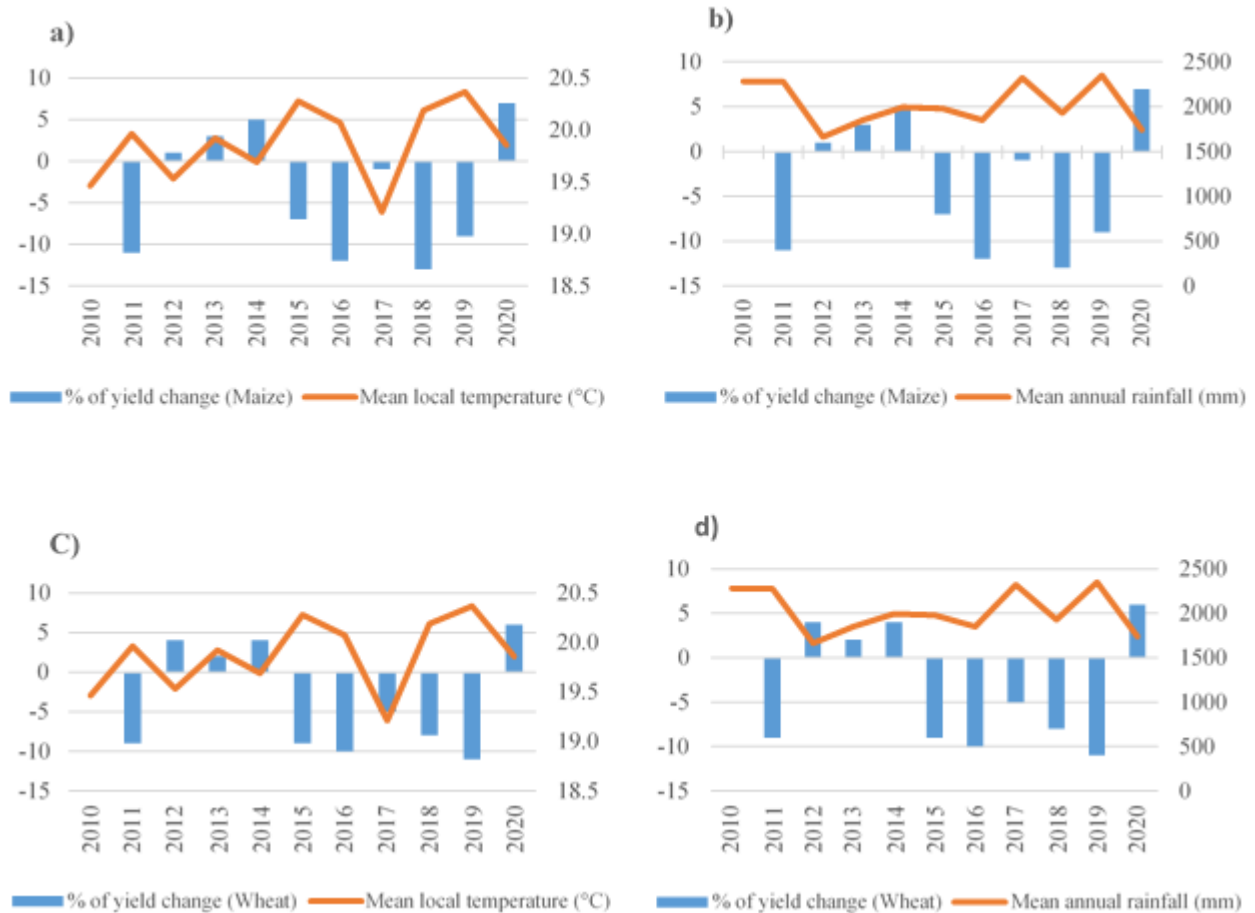


Figure 9: Cereals yield with temperature and rainfall trends (2010-2020)

Cereal yields over ten consecutive years were recorded from respective agricultural offices. The changes in yields for major crops were reduced to 13% for maize in 2018 and 11 % for wheat in 2019 (Fig. 8). A sharp rise in temperature from 19.4°C in 2017 to 20.4°C in 2019 was also recorded. The average annual rainfall has risen from 1700 mm/year in 2012 to 2,400mm/year in 2019. These variabilities in temperature and rainfall trends might have been one of the major factors that contributed to the reduction in crop production.

The increasing trend of seasonal and annual temperature over the study period might have an overwhelming impact on the processes of crop production of smallholder farmers (Rettie et al., 2022). A report by (Lemi, 2019) indicated that warming will promote the impact of droughts, decreasing the availability of soil moisture, which eventually influences cropland productivity. Tarkegn & Jury, (2020), and Mann & Warner, (2017) estimated that an increase in seasonal and annual temperature reduces crop yield per hectare.

The feedback from key informant interviews with agricultural experts and focus group discussions with community elders indicated that changes in rainfall patterns and variability affected their farming practices. It was confirmed that late onset and early cessation but abundant rainfall in recent years has declined crop yields by creating favorable conditions for insect pest proliferation and disease attack. And hence, farmers are shifting from rain-fed farming to early maturing varieties of small-scale irrigation-based diversified agriculture to sustain their livelihoods.

Generally, achieving triple wins of CSA, which are enhanced productivity, increased resilience, and reduced emission will be impaired as a result of the impact of weather variabilities. This is due to the fact that crop production has a limited tolerable range of temperature and rainfall (Tarkegn & Jury, 2020). Additionally, Adeg0 et al. (2019) indicated that temperature and rainfall variability could drastically decrease crop production and in some circumstances cause crop failure (Seyoum et al., 2013). Vulnerability to drought, pests, and diseases as a result of erratic weather patterns has reduced the capacity of smallholder farmers to adapt themselves to climate-related risks and shocks (World Bank, 2011). Agricultural land expansion and facilitated deforestation for diversifying household income sources, which are termed maladaptation, increase the amount of greenhouse gas (GHG) emissions to the atmosphere (Sanjeevaiah, et al., 2021). Sustainable productivity, improving community resilience for climate change adaptation, and reducing GHG emissions, which are fundamental pillars of climate-smart agriculture can be affected due to these changes in rainfall and temperature patterns.

3.6 Conclusion and recommendation

Long-term rainfall and temperature data (1986-2020) were collected and subjected to different meteorological indices analyses to see spatio-temporal variabilities and their potential impacts on agricultural production. The results indicated rainfall and temperature variations in time and space. Great variation in rainfall and temperature was recorded ranging from 1742 mm in Gojeb station to 2261 mm in Bonga station with its corresponding coefficient of variation of 27.3% and 24.5%, respectively. During the study period, the distribution of rainfall resulted in having a high coefficient of variation and increasing greater distribution irregularity. It was found that annual and winter rainfall showed a significant increase in rainfall but summer rainfall exhibited a non-significant rainfall increase. Increased frequency of positive rainfall especially in the winter season and in the last three and half decades has been another manifestation of high intensity of rainfall and elevated temperature. These trends over the different seasons strongly affected agricultural production and productivity. These anomalies in temperature and rainfall created a conducive environment for insect infestation and crop disease prevalence. It is, then, essential to design practical adaptation and mitigation approaches to reduce potential impacts on agricultural practices across different livelihood zones. This study recommends designing and implementing area-specific adaptation and mitigation strategies to minimize the climate change impacts on the local livelihoods and national food security on a bigger scale. Small-scale irrigation, poultry farming, sheep and goat fattening, modern animal husbandry, efficient inorganic fertilizer use, organic fertilizer use, crop residue management, conservation agriculture, using high yielding improved crop varieties, and using disease-resistant varieties could be an option to feed the growing population.

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CHAPTER 4: ROLE OF ADOPTION OF CLIMATE-SMART AGRICULTURE
ON FOOD SECURITY IN A MIXED FARMING SYSTEM OF GESHY
WATERSHED, SOUTHWEST ETHIOPIA

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ROLE OF ADOPTION OF CLIMATE-SMART AGRICULTURE ON FOOD SECURITY IN A MIXED FARMING SYSTEM OF GESHY WATERSHED, SOUTHWEST ETHIOPIA

4.1 Abstract

The traditional rain-fed agriculture system of Ethiopia is suffering from climate change impacts and extremes. It needs to be improved to feed the growing population and create a resilient society. Climate-smart agriculture (CSA) is an approach intended to sustainably increase productivity, enhance household resilience, and reduce greenhouse gas emissions. This study was, therefore, undertaken to examine how the adoption of multiple climate-smart agriculture (CSA) practices improve food security of smallholder farmer households in a moist tropical montane ecosystem of Southwest Ethiopia. Semi-structured questionnaires were used to collect data from 384 purposively selected households using a cross-sectional study design. Fifteen key informant interviews and eight focus group discussions were also conducted to triangulate the reliability of the survey data collected. A total of eighteen CSA practices, adopted by farmers, were identified in the study area. These practices were further grouped into five packages by using principal component analysis and linked to food security by the multinomial endogenous switching regression model. The findings revealed a great variation in the proportion of households using CSA practices where 92.3% were using crop management practices (use of efficient inorganic fertilizer, changing planting date, crop rotation using legume etc.) whereas 11.2% were using soil and water conservation practices. The study found out that the highest impact of CSA adoption on food security was by households that adopted all the five category practices. Adopters of this package were 41.2% more food secured in terms of per capita annual food expenditure, 39.8 percent in terms of Household Food Insecurity Access Scale (HFIAS), and 12.1 percent in terms of Household Food Consumption Score (HFCS) than the non-adopters. The adoption of this package was positively influenced by farm size, gender, and productive farm asset values. In nut shell, using CSA practices in combinations and to a relatively larger extent has the potential to alleviate food security problems.

Keywords: Climate-Smart Agriculture, Adoption, Food security, smallholder farmers, Geshy watershed

4.2 Introduction

In the era of climate change, climate-smart agriculture was first launched in 2009 as an approach to guide the management of agriculture (Ramachandran et al., 2015). The impact on sustainable food production, resilience, and mitigation can best be addressed by this approach (Grote et al., 2021). The primary indicators of climate change are increasing temperature, rising sea levels, melting ice caps, changing rainfall patterns, and changing humidity (IPCC, 2021). Secondary consequences that are direct determinants of agriculture are tidal surges, cyclones, floods, soil salinity, and droughts (Hasan et al., 2018). A crop model for sub-Saharan Africa forecasts that the adverse effect of crop damage on yields could be 36 percent, 12 percent, and 13 percent for Ethiopia, Rwanda, and Uganda respectively (Thomas, 2020). Hence, climate change has noticeable negative impacts on food security (Atanga & Tankpa, 2021; Ilboudo Nébié et al., 2021; Mekonnen et al., 2021). Thus, the prioritization of food security in a changing climate has been subjected to discussions at all levels of government (Tefera et al., 2022). Climate-smart agriculture is recommended by development organizations and researchers in order to feed the growing population under scenarios of the declining yield of major crops.

Ethiopia is a victim of the global climate change phenomenon despite its negligible per capita CO₂ emission, which is only 0.15 tons as compared to the global average of 4.79 in 2020 (Caporale et al., 2021). Ethiopia has experienced an increasing trend in average temperature (Belay et al., 2021; Gemedda et al., 2021). It is also obvious that dry seasons will get drier and wet seasons wetter (Gemedda et al., 2021). The study area is experiencing early cessation, a delayed onset, abundant rainfall, and poor *belg* performance making the watershed food insecure and forcing farmers to shift to livestock production, and grow short-maturing and lower-yielding varieties

The economy of Ethiopia is yet dependent on undeveloped rain-fed agriculture, which accounts for 80 percent of exports, 40 percent of GDP, and an estimated 75 percent workforce of the country (Eshete et al., 2020). Crop yields below the regional average, only 5 percent of irrigated land, weak market linkage, and limited use of improved seeds and fertilizers are common characteristics of Ethiopian agriculture (Alemu et al., 2019). Based on the Worldometer report of the United Nation, the population of Ethiopia has risen by 49 percent in the last 20 years alone and reaches approximately 122 million in 2022 while the agricultural system has not been improved since this time (CIAT, 2017). The agrarian population constitutes 85 percent of the total population and the

food security and livelihood situations are worsening (Tesfaye et al., 2021). These problems are yet exacerbated by global climate change impacts and extremes in the form of rainfall pattern anomalies and temperature rise (Gangadhara Bhat & Moges, 2021).

Climate-Smart agriculture (CSA) is currently promoted as an approach that reduces climate change impacts on the agriculture sector and ensure a more resilient and food secure community worldwide. The most cited definition of the concept of CSA as highlighted by Lipper et al. (2014) is ‘an approach for transforming and reorienting agricultural systems to support food security under climate change realities’. In a fluctuating climate, CSA can sustainably improve productivity and resilience (adaptation), remove/reduce greenhouse gas emissions (mitigation), and promote the efforts of national food security (Steenwerth et al., 2014; Thornton et al., 2018). Available literature documented that CSA practices can improve the productivity of crops and hence contribute to food security (Chemura et al., 2021; Habtewold, 2021; Teklewold et al., 2019). More than a quarter of the population of Ethiopia is food insecure. Ethiopia is ranked 90th out of 116 countries and categorized as serious in the 2021 Global Hunger Index (WFP, 2022). While CSA is an important approach for the resource poor and highly vulnerable agrarian society such as Ethiopian smallholder farmers, the establishment of the direct link between food security and CSA practices adoption has received little attention to date (Hasan et al., 2018).

Traditionally, smallholder farmers, through their indigenous knowledge, have been undertaking farming practices/CSA such as agroforestry, soil fertility management using organic manure, soil and water conservation, and crop rotation. This experience, though not in the name of CSA, laid a foundation for current CSA technology knowledge. These practices were then scaled up to fulfill the three pillars of CSA; sustainably increasing agricultural productivity, enhancing household adaptation to climate change impacts, and reducing greenhouse gas emissions and promoted as CSA practices by the government and other research organizations (FAO, 2014; Steenwerth, 2014; Thornton et al., 2018). Thus, in Ethiopia, some of the CSA practices that have been implemented include integrated soil fertility management, integrated watershed management, conservation agriculture, sustainable land management, crop residue management, agroforestry, improved livestock feed, composting and rangeland management (CIAT, 2017; Tesfaye et al., 2021; Autio et al., 2021).

In Ethiopia, the adoption of CSA practices remains low. Initial investment failures due to lack of financial resources and the available land tenure insecurity are contributing to the low adoption. Theoretically, to adopt a single or combination of CSA practices, farmers need to maximize profits (Mekonnen et al., 2021) and this is highly associated with the theory of utility that states: the choice being made to adopt a certain technology is whether an alternative has a greater utility than another (Terdo & Adekola, 2014).

To increase the uptake of CSA practices, a better knowledge of factors that determine farmer's adoption behavior is crucial for developing working policy. Empirical evidence showed that CSA adoption by smallholder farmers is influenced by farm characteristics, socioeconomic, access to important infrastructure services, institutional, technology and information, climate related and social capital factors (Steenwerth et al., 2014; Wekesa et al., 2018; Kangogo et al., (2021).

Previous studies on CSA practices adoption in Ethiopia focused mainly on factors influencing a specific CSA practice. Nevertheless, a variety of technologies that can be used in combination, are frequently presented to farmers to address climate change impacts and ensure sustainable food security. Thus, one of the contribution of this study is CSA practices adoption modelling while considering the interrelatedness between them. In addition, farmers adopt various level of CSA practices (Habtewold, 2021). Evaluating the level/intensity of adoption of CSA practices using Multinomial Endogenous Switching Regression model is the other contribution of this paper. The determinant factors influencing CSA adoption is also the other contribution of this paper.

This study is thus aiming at investigating the level of adoption of CSA technologies, adoption patterns among different household typologies and factors influencing adoption of CSA in Geshy watershed of Southwest Ethiopia.

4.3 Materials and methods

4.3.1 Theoretical framework

The theory of utility that describes the decision on whether or not to adopt any CSA practice lies under the benefit and utility maximization is used as the theoretical framework in this study (Terdo & Adekola, 2014). The assumption is that economic agents, including smallholder farmers, adopt CSA practices when the net benefit or expected utility is significantly higher than when those that do not adopt (Green, 2012). The activities of economic agents could be observed through farmers' choices, as the utility cannot be directly observed. Assume a rational farmer

whose objective is to maximize productivity over a certain period and has a set of CSA practices of j alternatives to choose from. The i farmer decides to adopt j CSA practice if the j utility is perceived to be higher than that from other alternatives (assume, k). This relationship is presented as Equation (9):

$$U_{ij} = (\beta' j X_i + \varepsilon_j) > U_{ik} (\beta' k X_i + \varepsilon_k), k \neq j \quad (9)$$

Where U_{ij} and U_{ik} represent the perceived utility by i farmer from CSA practices options j and k , respectively; X_i is a vector regressor that affects the CSA alternative the farmer chooses; $\beta' j$ and $\beta' k$ are independent variable parameters; and ε_j and ε_k are terms of errors, which with regard to the economic assumption are identically and independently distributed (Brooks, 2019).

Under the assumption of preference that the farmer decides to adopt a CSA practice option that generates net benefits and does not adopt and practice otherwise, the discrete observable choice of practice can be associated with the latent continuous variable of net benefit as Equation (10):

$$Y_{ij} = 1, \text{ if } U_{ij} > 0 \text{ and } Y_{ij} = 0 \text{ if } U_{ij} < 0 \quad (10)$$

In the formula generated, Y is a dependent binary variable valued as 1 when the farmer chooses for a CSA practice and 0 if otherwise. The probability that the i farmer will choose j CSA practice option among a number of adaptation alternatives could be expressed as Equation (11):

$$\begin{aligned} \left(X = \frac{1}{x}\right) &= P\left(U_{ij} > \frac{U_{ik}}{x}\right) = P\left(\beta' j X_i + \varepsilon_j - \beta' k X_i - \varepsilon_k > \frac{0}{x}\right) \\ &= P\left(\beta^* X_i + \varepsilon^* > \frac{0}{x}\right) \\ &= F(\beta^* X_i) \end{aligned} \quad (11)$$

Where P is a probability function; $\varepsilon^* = \varepsilon_j - \varepsilon_k$ is a random error term; $\beta^* = (\beta' j - \beta' k)$ is an unknown vector parameter that can be justified as the net impact of the choice of CSA practice determinants; and $F(\beta^* X_i)$ is a cumulative ε^* distribution estimated at $\beta^* X_i$ (Brooks, 2019).

4.3.2 Analytical framework

Primarily, the currently available 18 CSA practices adopted by farmers: small-scale irrigation, alley cropping, use of organic fertilizer, use of improved crop varieties, use of efficient inorganic fertilizer, planting trees for windbreak and shelter for crops, use of mulching, changing planting dates, use of cover crops, crop rotation using legumes, improved animal husbandry, poultry

farming, use of terraces, apiculture, feed improvement, sheep fattening, use of grasses, and use of bio-briquettes, were identified during the household survey assessments and personal observation results. During the assessment, the Global Green Growth Institute (GGGI) compendium of CSA practices framework (GGGI, 2021) and the Food and Agricultural Organizations of United Nation (FAO) database (FAO, 2014) were used to confirm whether the available practice is climate-smart or not. Seven of the available CSA practices have previously been traditionally practiced by smallholder farmers and the remaining 11 practices are being promoted by the government through its extension channels in the study area. Then, using principal component analysis (PCA), these practices were further grouped into five packages of heterogeneous principal clusters: 1) crop management practices, 2) field management practices, 3) farm risk reduction practices, 4) supplementary income generation practices, and 5) soil and water conservation practices. Principal component analysis helps group smaller number of highly correlated practices under one component for the ease of interpretation and generalization of the group (Jolliffe & Cadima, 2016; Wekesa et al., 2018). The rotation resulted in 5 principal components among a possible 18 extracted with eigenvalues >1 based on [36] criterion. The principal component analysis is helpful in minimizing the dimensionality of data without losing much information. This is relevant in determining the relationships between practices with regard to usage and succeeding analysis through fitting the groups to the model and drawing conclusions. The method is superior to a conventional grouping of technologies that could make it hard to conclude about the group in conditions where the entire group is represented by few practices. Finally, a comparison between the impact of CSA adopters and non-adopters on food security status is computed using multinomial endogenous switching regression analysis.

Using principal component analysis with varimax rotation and iteration, the practices were grouped in the model shown in Equation (12):

$$Y_1 = a_{11}x_{12} + a_{12}x_2 + \dots + a_{1n}x_n \quad (12)$$

$$Y_j = a_{j1}x_{j1} + a_{j2}x_2 + \dots + a_{jn}x_n$$

Where Y_1, \dots, Y_j represents uncorrelated principal components, $a_1 - a_n$ indicates correlation coefficient and X_1, \dots, X_j signifies factors affecting the choice of a particular strategy. The identified CSA practices are grouped using principal component analysis and presented in Table 1. Prior to

the field study, the identification of these practices was guided by the Ethiopian CSA roadmap document ratified by the Ministry of Agriculture (Eshete et al., 2020).

The multinomial endogenous switching regression model (MNL) was then employed to model the determinants of choice and the impact of CSA practices on household food security after these practices are grouped.

Table 7: Definition of climate-smart agriculture (CSA) practices understudy

S/No	CSA practices	Definition	Why are these practices climate-smart
1	Small-scale irrigation	Irrigation on small plots, in which small farmers have the controlling influence of all activities (CIAT, 2014)	Create carbon sink and improve yield frequency
2	Practicing alley cropping	An agroforestry practice that places trees within agricultural cropland system (CIAT, 2017)	Diversify income sources
3	Use of organic fertilizer	Putting animal dung or manure on farmlands for soil fertility improvement (FAO, 2014)	Reduce nitrous oxide and methane emission
4	Use of improved crop varieties	Any variety that has been bred using formal plant breeding methods for enhancing yield (GGGI, 2021)	Improve productivity, reduce insect and disease attack
5	Use of efficient inorganic fertilizer	Application of optimum amount of artificial fertilizer for increasing productivity and reducing greenhouse gas emissions (Kumar et al., 2019)	Improves soil productivity
6	Planting trees for windbreak and shelter for crops	Planting trees around farmlands for reducing wind effects and providing protection (CIAT, 2017)	Providing shed to crops, trees store large amount of CO ₂ and diversify income sources
7	Use of mulching	Covering the soil between plants with material layer/s [18]	Reduces existing emissions
8	Changing planting dates	Adjusting the time of crop sowing in accordance with the onset of the rainy season (CIAT, 2017)	Reduce crop failure
9	Use of cover crops	Planting cover crops (FAO, 2014)	Maintain soil moisture and reduce emission
10	Crop rotation using legumes	Planting various crops on the same farmland in consecutive planting seasons (FAO, 2014)	Improves soil fertility and increases crop productivity
11	Improved animal husbandry	Transferring inherited superior traits from one animal to other of same species with an improved good feed conversion, growth rate, meat quality, high milk yield etc. (CIAT, 2017)	Improves household income
12	Poultry farming	Raising domesticated birds such as chickens, turkeys to produce meat or egg for food (GGGI, 2021)	Improve household income
13	Use of terraces	Physical or biological structures built to prevent soil loss from erosion by different agents (Alemu et al., 2019)	Reduced erosion and soil detachment
14	Apiculture	The scientific method of rearing honeybee (Ali & Erenstein, 2017)	Improve household income, pollination
15	Feed improvement	Improving animal diet to achieve more protein with less feed and lower emission (GGGI, 2021)	Improved livestock productivity
16	Sheep fattening	The feeding of nutrient-rich feed to stimulate rapid growth and fat deposition for targeted carcass growth and quality (GGGI, 2021)	Improve household income
17	Use of grass strip	Undisturbed areas of permanent vegetation around the edge or within fields (Habtewold, 2021)	Feed for animals, soil and water conservation
18	Use of bio-briquettes	A renewable fuel (briquette) with a combustion property prepared from coffee residual waste (Espuelas et al., 2020)	Energy-saving, reducing deforestation, mitigation role

Household food security status was computed using per capita annual food expenditure, Household Food Insecurity Access Scale (HFIAS), and Food Consumption Score (FCS) for measuring availability, access, and utilization dimensions respectively.

Smallholder farm households were assumed to face a choice of nine mutually exclusive packages/combinations for responses to changes in average rainfall and temperature (climate change) in the first stage. In the next stage, MNLESR econometric model was used to examine the effect of various CSA practices on the status of food security.

Step 1: Multinomial adoption selection model

At this point, the determinants of the choice of CSA packages were determined by using the multinomial logit model. Multinomial logit model assumes that the odds of preferring one class of CSA technology over another do not depend on the presence or absence of other irrelevant alternatives (IIA), which is not always desirable (Hoffman & Duncan, 2018). As a result, farm households were assumed to maximize the status of their food security Y_i by making revenue comparisons generated by 9(M) alternative CSA packages. The need for farmer i to make a choice over any strategy j over other alternatives K is that $Y_{ij} > Y_{ik}$, $K \neq J$, where j gives higher expected food security than any other technology. Y_{ij}^* is the latent variable representing the level of expected food security that can be affected by the observed household, plot features, climate shocks, and unobserved characteristics as follows using Equation (13):

$$Y_{ij}^* = X_i \beta_j + \varepsilon_{ij} \quad (13)$$

Where X_i denotes the observed exogenous variables (household and plot features), while the unobserved features are justified by the error term ε_{ij} . X_i is the covariate vector, which is assumed to be uncorrelated with the idiosyncratic unobserved stochastic component ε_{ij} , that is $E(\varepsilon_{ij}|X_i) = 0$, in that error terms ε_{ij} are considered to be identically independent and Gumbel distributed, which is, under the independent irrelevant alternatives (IIA) hypothesis (Fosgerau et al., 2020). The probability of choosing $j(P_{ij})$ is given by the multinomial logit model (Hoffman & Duncan, 2018) following the selection model as follows in Equation (14):

$$P_i = p(\varepsilon_{ij} < 0|x_i) = \frac{\exp(X_i \beta_i)}{\sum_{K=0}^J \exp(X_i \beta_k)} \quad (14)$$

Step 2: Multinomial endogenous switching regression model

The impact of each response package on food security was examined using endogenous switching regression (ESR) by applying (Hoffman & Duncan, 2018) selection bias correction model. A total of 9 regimes have been faced by farm households with regime $j = 1$ being the reference non-responsive category. For each possible regime, the food security status equation is defined in Equation (15) as:

$$\begin{aligned} \text{Regime 1 } Q_{i1} &= Z_i \alpha_1 + \mu_{i1} \text{ if } i = 1 & (15) \\ &\vdots & \\ &\vdots & \\ \text{Regime j } Q_{ij} &= Z_i \alpha_j + \mu_{ij} \text{ if } i = j \end{aligned}$$

Where Q_{ij} 's denote the status of food security, Z_i represents a list of exogenous variables (household, plot, location, climate shocks, and institutional variables), and the i^{th} farmer in regime j and the distribution of error terms μ_{ij} 's are with $E(\mu_{ij}|x, z) = 0$ and $\text{var}(\mu_{ij}|x, z) = \sigma_j^2$. The term Q_{ij} is observed if, and only if, CSA technology is used, which happens when $Y_{ij}^* > \max_{K \neq 1} (Y_{ik})$; if Equation (14) and (15) error terms are not independent, OLS estimates were biased for Equation (15). A α_j consistent estimation needs inclusion of alternative choices selection correction terms in Equation (14). The following linearity assumption is considered in MNLSR: $E(\mu_{ij}|\varepsilon_{i1} \dots \varepsilon_{ij}) = \sigma_j \sum_{k \neq j}^j r_j(\varepsilon_{ik} - E(\varepsilon_{ik}))$. The correlation between error terms in Equation (14) and (15) was zero by construction.

Equation (14) can be expressed by using the above assumption as follows:

$$\begin{aligned} \text{Regime 1 } Q_{i1} &= Z_i \alpha_1 + \sigma_1 \lambda_1 + \omega_{i1} \text{ if } i = 1 & (16) \\ &\vdots & \\ &\vdots & \\ \text{Regime j } Q_{ij} &= Z_i \alpha_j + \sigma_j \lambda_j + \omega_{ij} \text{ if } i = j \end{aligned}$$

Where σ_j is the covariance between μ 's and ε 's, while λ_j is the inverse Mills ratio calculated from the estimated probability in Equation (16) as:

$$\lambda_j = \sum_{m \neq j}^j \rho_j \left[\frac{P_{ik} \ln(P_{ik})}{1 - P_{ik}} + \ln(p_{ij}) \right] \quad (17)$$

Where ρ signifies the correlation coefficient of μ 's and ε 's, whereas ω_{ij} are error terms with zero expected value. In the earlier expression of the multinomial choice setting, there were one $j - 1$

selection correction terms for each CSA alternative practice. To account for the heteroscedasticity arising from regressors generated given by λ_i , the standard errors in eq. (16) were bootstrapped.

Average treatment effects estimation

At this stage, a counterfactual analysis was conducted to examine average treatment effects (ATT) by making a comparison of the expected outcomes of adopters with and non-adopters of CSA technology as described in Equation (18a, 18b, 19a, and 19b). In the counterfactual and actual scenarios, ATT was computed as follows (Liang et al., 2021) in Equation (20):

Status of food security with adoption/usage

$$E(Q_{i2}|i = 2) = z_i\alpha_2 + \sigma_2\lambda_2 \quad (18a)$$

$$E(Q_{ij}|i = j) = z_i\alpha_j + \sigma_i\lambda_j \quad (18b)$$

Status of food security without adoption (counterfactual)

$$E(Q_{i1}|i = 2) = z_i\alpha_1 + \sigma_1\lambda_2 \quad (19a)$$

$$E(Q_{i1}|i = j) = z_i\alpha_1 + \sigma_1\lambda_j \quad (19b)$$

The difference between 18a and 19a defines ATT, which is given by:

$$\begin{aligned} ATT &= E(Q_{i2}|i = 2) - E(Q_{i1}|i = 2) \\ &= z_i(\alpha_2 - \alpha_1) + \lambda_2(\rho_2 - \rho_1) \end{aligned} \quad (20)$$

It shows the expected change in mean food security status of adopters, if adopters and non-adopters have the same features of return, for example, while λ_j is the selection term that considers all the differences in potential effects of unobserved variables if adopters had the same features as non-adopters.

Table 8 presents variables employed in econometric analysis, which was derived from reviewing past studies (Habtewold, 2021; Hasan et al., 2018; Lipper et al., 2014; Wekesa et al., 2018).

4.3.3 Food security measurement

The status of household food security was measured using per capita annual food expenditure, Household Food Insecurity Access Scale (HFIAS), and Household Food Consumption Score (HFCS), which were used as proxies for the food security of farmers. The per capita annual food

expenditure is an indicator that approximates calorie consumption based on the total amount of food acquisition or consumption by the household. By attaching standard nutritional value weights in the index of the food groups, the indicator constructs the conversion of the food acquisition or consumption by the household into dietary energy (K/cals) by matching individual foods with the food consumption table. The amount of calories is calculated by measuring the portion consumed or purchased, divided by the total household members (Nicholson et al., 2021). If the data is collected over a number of days, the computation needs to be divided by the number of collection days in order to generate the number of calories per person per day. HFIAS was developed by the USAID-funded Food and Nutritional Technical Assistance II Project (FANTA) and measures the access dimension. It contains nine occurrence questions with severity based on four levels of questions on a recall period of the previous month. A range of questions (0 = not at all, 1 = rarely, 2 = sometimes, 3 = often) are represented by the four severity questions. The highest household score is 27, indicating severe food insecurity; the lowest score is 0, which shows that the household is food secure (Otekunrin et al., 2021). The HFCS was developed by World Food Programme (WFP) and measures the utilization dimension. It incorporates the frequency of consumption of diets over a seven-day period and weighs according to the relative nutritional value of the food group consumed. For instance, nutritionally dense foods such as animal products are given higher weights than foods such as tubers that contain lesser nutritionally dense foods. According to this score, household food consumption can be further grouped into three classifications: poor, borderline, or acceptable (Douyon et al., 2022; Wiesmann et al., 2009).

Table 8: Variables employed in econometric analysis

Variable	Description	Measurement	Mean	SD
FOODSEC	Household food security status	Per capita annual food expenditure	0.98	0.21
		Food Insecurity Access Scale	16.21	7.13
		Food Consumption Score	65.71	12.64
AGE	Age in years of head of the household	Continuous	39.43	17.41
GENDER	Gender of the head of the household	Dummy = 1 if male, 0 = female	0.65	-
EDUC	Years of education of the head of the household	Discrete	6.00	2.13
H/SIZE	Number of household members	Discrete	5.34	3.14
OFF-FARM	Off-farm employment participation	Dummy = 1 if yes, 0 = otherwise	0.31	-
ASSETS	Productive farm assets values (in Ethiopian Birr which is equivalent to \$0.017.	Continuous	67,144.12	69,154.32
LAND	Farm size owned in acres	Continuous	1.51	2.34
TERRAIN	Terrain of the land	1= sloppy, 0 = otherwise	0.72	-
S/FERTILITY	Soil fertility status	1 = poor, 2 = medium, 3 = fertile	2.12	-
EROSION	Soil erosion severity	1 = severe, 2 = moderate, 3 = low	2.77	-
FLOOD	Experience of flooding in the past 5 years	Dummy = 1 if yes, 0 = otherwise	0.67	-
RAINS	Experience of insufficient rainfall in the past 5 years	Dummy = 1 if yes, 0 = otherwise	0.89	-
H/STRMS	Experience of hailstorms in the past 5 years	Dummy = 1 if yes, 0 = otherwise	0.43	-
DISTNCE	Walking time in minutes to input and output market	Continuous	57.31	25.43
EXTN	Number of contacts with extension agents annually	Discrete	16.51	4.52
GRPMSHIP	If the farm household is a member of a farm-related association	Dummy = 1 if yes, 0 = otherwise	0.54	-
CREDIT	Whether credit is received by the household	Dummy = 1 if yes, 0 = otherwise	0.72	-

4.4 Results and discussion

4.4.1 Principal component analysis

Table 3 comprises principal components (PCs) and linear combination coefficients known as loadings. In using principal component analysis, the identified eighteen CSA practices are reduced into five components that contain all the CSA practices, which is based on (Jolliffe & Cadima, 2016). These components are abbreviated as Comp1, Comp2, Comp3, Comp4, and Comp5 that represent crop management practices, field management and climate change mitigation practices, farm-risk reduction practices, supplementary income generation practices, and water conservation practices, respectively. Inspection of Table 9 visually reveals that the total variability of the data set is 85% explained by the five PCs. The PCA results greatly explained the data and the results presented in table 3 are considered a good fit. The first component explained 37.2% variance and it is correlated with the use of efficient inorganic fertilizer, changing planting date, crop rotation using legumes, and use of organic fertilizer all with positive effects (factor loadings). Accordingly, this component was named crop management practices.

Table 9: Effects of the five components of CSA compositions

Strategies	Comp1	Comp2	Comp3	Comp4	Comp5	Communality
Irrigation	0.6347	0.4997	0.6992	0.6631	0.2741	0.7070
Planting crops on tree lands	0.5327	0.6217	0.2271	0.1173	-0.3325	0.6170
Use of organic fertilizer	0.2178	0.3184	0.3112	0.3312	0.1192	0.6915
Use of improved crop varieties	0.5718	-0.2998	0.5513	0.5538	-0.2174	0.6614
Use of efficient inorganic fertilizer	0.5561	0.2117	0.4828	0.2217	-0.3715	0.6618
Planting trees on croplands	0.3691	-0.2511	0.1735	0.3721	0.2721	0.6516
Use of mulching	0.1998	0.5771	0.5122	-0.3351	0.2193	0.6113
Changing planting dates	0.6978	0.4112	0.2172	-0.2935	-0.4271	0.6925
Use of cover crops	0.2975	0.5523	0.7314	-0.4152	0.2221	0.6115
Crop rotation using legumes	0.7173	0.1192	-0.3142	-0.1184	-0.4416	0.7110
Cattle fattening	0.2756	-0.5532	0.3352	0.6824	-0.4618	0.6001
Poultry farming	0.3291	-0.4992	0.2741	0.5962	-0.6144	0.6591
Making terraces	0.2531	0.1184	-0.4472	-0.4997	0.7142	0.6481
Apiculture	0.4438	-0.3351	0.3624	0.5478	-0.5921	0.6284
Feed improvement	0.1962	-0.4463	-0.1178	-0.3182	-0.3726	0.6002
Sheep fattening	0.2749	-0.3172	0.2913	0.3824	-0.4426	0.6131
Planting grasses	0.2111	-0.1172	-0.6812	-0.6172	0.6927	0.6005
Use of briquettes	0.1175	0.5247	-0.4711	-0.3153	-0.2226	0.6317
Eigenvalues	4.8153	3.116	1.9925	2.2241	1.1420	
Eigenvalues (%) contribution	37.2113	25.1711	10.6327	6.4118	5.2461	
Cumulative (%)	37.2113	62.3824	73.0151	79.4269	84.673	

Principal component (PC) 1, 2, 3, 4, and 5 accounted for 37.2, 25.17, 10.63, 6.4, and 5.2% variances respectively. This signifies the first five components have great importance in explaining variance in the data set. The second PC was related to the use of cover crops, planting crops on tree lands, planting trees on croplands, use of mulching, and use of briquettes where they all have positive loadings too. Component 2 was termed as field management and climate change mitigation practices. The third PC comprised feed improvement, use of improved crop varieties, and use of cover crops, irrigation with corresponding positive effects, which are collectively called farm risk reduction activities. The fourth PC consists of the use of fattening, apiculture, and poultry farming which had similar positive effects. These practices were together known as supplementary income generation practices. Finally, the last PC was related to planting grasses and making terraces where they have positive loadings. PC 5 was collectively called soil and water conservation practices.

The communality column indicates the total size of variance of each variable retained in the five components (Alavi et al., 2020) described that all items in PCs need to have communalities of over 0.60 or 0.7 average communality for small samples precisely below 50 to justifiably say a PCA is

performed. With a 384-sample size, Table 9 presented a variance greater than 60% in the PCs and can be considered as meeting the minimum criteria. For PCs interpretation, variables with high communalities and high factor loadings were justified from varimax rotation (Bartholomew, 2010; Jolliffe & Cadima, 2016).

The descriptive statistics of the composition of each component (climate-smart practices) are presented in Table 10. The most commonly used component used was crop management practices with 92.34% of smallholder farmers using a minimum of one unit of this component. The component consists of practices such as the use of efficient fertilizer, changing planting dates, crop rotation using legumes, and the use of organic fertilizer. The second component used greatly was field management and climate change mitigation.

Table 10: List of climate-smart agricultural strategies

Group	Users' percentage	Components
Crop management practices	92.34%	Use of efficient inorganic fertilizer Changing planting date Crop rotation using legumes Use of organic fertilizer
Field management and climate change mitigation practices	89.01%	Use of cover crops Alley cropping Tree planting for windbreak and shelter for crops Use of mulching Use of briquettes
Farm risk reduction practices	81.21%	Feed improvement Use of improved crop varieties Use of cover crops Small-scale irrigation
Supplementary income generation practices	42.24%	Improved animal husbandry Apiculture Poultry farming
Soil and water conservation practices	11.2%	Use of grass strip Use of terraces

practices used by 89.01%. This component comprised the use of cover crops, alley cropping, planting trees for windbreak and shelter for crops, use of mulching, and use of briquettes. The third component widely used by farmers was farm risk reduction activities which constituted 81.21% of responses from farmers that include practices such as feed improvement, use of improved crop varieties, use of cover crops, and small-scale irrigation.

Supplementary income generation practices were only used by 42.24% of farmers. The practices included under this component are improved animal husbandry, apiculture, and poultry farming. Finally, the least used component consisted of soil and water conservation practices, which include the use of grass strips and making terraces. This component was used by only 11.2% of farmers.

4.4.2 Econometric findings

The impact of CSA packages on food security is well understood following the computation of the determinants of the choice of CSA packages (Hirpa et al., 2020). The adoption of CSA practices in a wide range of combinations has implications on the status of food security smallholder households. With the set of available packages given, understanding the factors deriving an individual to choose a specific package is crucial for policy direction (Wekesa et al., 2018).

The various combinations of packages are presented in Table 11 whereby 8 out of 25 possible combinations were used by farmers. A relatively small proportion of farmers (9.37%) were non-adopters/non-users of any CSA package. About 3.92% of farmers used the $C_0F_0R_1I_1S_1$ package. This package is composed of risk reduction practices, income-generating practices, and soil and water conservation practices. Another 6.26% used the $C_1F_1R_1I_0S_1$ package that comprised crop management practices, field management and climate change mitigation practices, risk reduction practices, and soil and water conservation practices. Further, 6.52% of farmers used $C_1F_0R_0I_0S_0$ packages that consisted of crop management practices only. Another 7.29% of farmers used $C_1F_0R_1I_0S_1$ packages that contained crop management practices, risk reduction practices, and soil and water conservation practices. About 8.34% of farmers used the $C_1F_0R_1I_1S_1$ package which contained crop management practices, risk reduction practices, income-generating practices, and soil and water conservation practices. Again, 9.13% used the $C_1F_1R_1I_0S_0$ package that comprised practices of crop management, field management, and risk reduction. Approximately 10.16% used all the five packages ($C_1F_1R_1I_1S_1$) together.

The largest proportion of farmers (39.01%) used the $C_1F_0R_1I_1S_0$ package that contained crop management activities, farm risk reduction practices, and income regeneration practices. This indicates the efforts of many subsistence farmers to achieve food security are based on irrigation-based crop management practices despite anomalies in rainfall patterns. The observation is similar to the findings of Hasan et al. (2018) that recommended that farmers in the region undertake such self-initiated responsive strategies for survival amidst adverse climate change impacts. A careful

observation of Table 5 shows that all users of CSA practices (66.6% of all farmers) used a pack of practices with the inclusion of crop management practices. This observation indicates the need of the majority of farmers to meet their fundamental crop production for food production and this is in conformity with the study conducted by (Hoffman & Duncan, 2018).

4.4.3 Determinants of specific CSA packages choice

The factors that influence the choice of CSA packages are described in this section. It is then followed by quantification of the effect of package use on the status of farm household food security in the last stage. This was generated using the multinomial endogenous switching regression (MNLESR) model, which is a model of two-stage regression analysis. The first stage of MNLESR entails the determination of the choice of CSA strategy using the multinomial logit model. This is a crucial step as it guides the appropriate intervention to enhance the adoption of CSA packages. The next stage determines the impact of CSA packages use on household food security. The marginal effects from the MNL model that measured the probability of the expected change of a particular CSA strategy choice being made with respect to a unit change in an independent variable, which is presented in Table 6.

Non-adopters of all practices ($C_1F_1R_1I_1S_1$) were the base category compared to the other 9 packages (refer to Table 7 for the packages) used by smallholder farmers. The result presented nine sets of parameter estimates, one for each are strategies mutually exclusive. The Wald test is rejected for all regression coefficients are jointly equal to zero [$X^2(500) = 552.41; p = 0.000$]. Thus, the results indicate that across the alternative packages, the estimated coefficients differ substantially and this result was similar to the study findings of (Ali & Erenstein 2017; Douyon et al., 2022; Hirpa et al., 2020; Liang et al., 2021) that state the variabilities of estimated coefficients in the adoption of multiple CSA package choices of small-scale farmers differ significantly.

Table 11: Combination of CSA strategy specifications to form the packages

Choice (j)	Binary quadruplicate	C = Crop management		F = Field management		R = Risk reduction		I = Income generation		S = Soil & water conservation		Frequency	Percentage
		C ₀	C ₁	F ₀	F ₁	R ₀	R ₁	I ₀	I ₁	S ₀	S ₁		
1	C ₀ F ₀ R ₀ I ₀ S ₀	✓		✓		✓		✓		✓		36.00	9.37
2	C ₀ F ₀ R ₀ I ₀ S ₁	✓		✓		✓		✓			✓	0.00	0.00
3	C ₀ F ₀ R ₀ I ₁ S ₁	✓		✓		✓			✓		✓	0.00	0.00
4	C ₀ F ₀ R ₁ I ₁ S ₁	✓		✓			✓		✓		✓	15.00	3.92
5	C ₀ F ₁ R ₁ I ₁ S ₁	✓			✓		✓		✓		✓	0.00	0.00
6	C ₁ F ₁ R ₁ I ₁ S ₁		✓		✓		✓		✓		✓	39.00	10.16
7	C ₁ F ₁ R ₁ I ₁ S ₀		✓		✓		✓		✓		✓	0.00	0.00
8	C ₁ F ₁ R ₁ I ₀ S ₀		✓		✓		✓	✓			✓	35.00	9.13
9	C ₁ F ₁ R ₀ I ₀ S ₀		✓		✓		✓	✓			✓	0.00	0.00
10	C ₁ F ₀ R ₀ I ₀ S ₀		✓	✓			✓	✓			✓	25.00	6.52
11	C ₀ F ₁ R ₀ I ₀ S ₀	✓			✓		✓		✓		✓	0.00	0.00
12	C ₁ F ₀ R ₁ I ₀ S ₁		✓	✓			✓	✓			✓	28.00	7.29
13	C ₁ F ₀ R ₀ I ₀ S ₁		✓	✓			✓	✓			✓	0.00	0.00
14	C ₁ F ₀ R ₀ I ₁ S ₁		✓	✓			✓		✓		✓	0.00	0.00
15	C ₀ F ₁ R ₀ I ₀ S ₀	✓			✓		✓	✓		✓		0.00	0.00
16	C ₁ F ₁ R ₀ I ₀ S ₁		✓		✓		✓	✓			✓	0.00	0.00
17	C ₁ F ₀ R ₁ I ₁ S ₁		✓	✓			✓		✓		✓	32.00	8.34
18	C ₀ F ₁ R ₁ I ₁ S ₀	✓			✓		✓		✓		✓	0.00	0.00
19	C ₀ F ₀ R ₁ I ₀ S ₀	✓		✓			✓	✓			✓	0.00	0.00
20	C ₀ F ₁ R ₀ I ₀ S ₁	✓		✓			✓	✓			✓	0.00	0.00
21	C ₁ F ₀ R ₁ I ₁ S ₀		✓	✓			✓		✓		✓	150.00	39.01
22	C ₀ F ₁ R ₁ I ₀ S ₁	✓			✓		✓	✓			✓	0.00	0.00
23	C ₀ F ₁ R ₀ I ₀ S ₀	✓			✓		✓	✓		✓		0.00	0.00
24	C ₁ F ₁ R ₀ I ₁ S ₁		✓		✓		✓		✓		✓	0.00	0.00
25	C ₁ F ₁ R ₁ I ₀ S ₁		✓		✓		✓	✓			✓	24.00	6.26
Total												384	100

The possible CSA packages are represented by the binary quadruplicate. In the quadruplicate, each element is a binary variable for a CSA combination of crop management practices(C), field management and climate change mitigation practices(F), farm risk reduction practices (R), supplementary income generation practices (I), and soil and water conservation practices (S). Subscript 1 = adoption and 0 = otherwise

The determinant factors for CSA practices adoption is presented in Table 12. The age of the head of the household was negatively associated with the usage of the C₁F₀R₀I₀S₀ package and positively associated with C₁F₀R₁I₀S₀ at 5% and 10% significant levels, respectively. An increase in the age of the head of the household by one year minimizes the likelihood of using the C₁F₀R₀I₀S₀ package by 0.18% while enhancing the likelihood of using the C₁F₀R₁I₀S₀ package by 0.17%. This implies that as age mounts up, farmers shift from smaller packages of practices to larger ones and this is in conformity with the study conducted by (Wekesa et al., 2018). Older farmers may be afraid of risks associated with climate change and decide to diversify their income sources from their past experiences and thus accumulate many packages. Contrary, Ali & Erenstein (2017) documented that old age is negatively associated with the adoption of climate change adaptation strategies, justifying that agriculture is a labor-intensive task that demands a healthy, risk-bearing, and energetic farmer. Recent innovations may not reach older farmers as well

With respect to household gender, male-headed households were 3.1% more likely to use the C₁F₁R₁I₁S₁ package that contains all the CSA practices only at a 5% level of significance as relative

to $C_0F_0R_0I_0S_0$ (non-adopters of all practices) as compared to females. Women are generally resources and time-constrained. This may justify the inverse relationship with CSA practices usage under this study. A study by Autio et al. (2021) reported that one of the major barriers to CSA adoption is gender (females) stemming from gender roles customarily. Additionally, they described that access to resources such as inputs, land extension service, education, and credit to women is less than men where all of which can have important contributions to CSA transition. For female-headed households, land ownership presents another difficulty in CSA adoption.

The educational level of the household head negatively affected $C_1F_1R_1I_0S_0$ which comprises of crop management practices, field management and climate change mitigation practices, and risk reduction practices. The more educational years reduced the probability of using this package by a 5% level of significance. It might be due to the reason that this package never guarantees their resilience from prevailing climate change risks and opt-out this package as it doesn't fill this gap. A study by Kangogo et al. (2021) argues that an increased level of education tends to establish the ability and innovativeness to monitor risks by farmers for proper farm adjustments.

There exists a positive and significant relationship between the value of productive assets of farms (a wealth proxy) and CSA usage. Farmers endowed with resources (farmers with high value of productive farm assets) were more likely to use more packages $C_1F_1R_1I_0S_0$ and $C_1F_1R_1I_0S_1$ as opposed to non-adopters of any package. For resource-endowed farmers, the probability of using these packages increased by 0.15% and 6.1%, respectively. It is likely that wealthier farmers have the capacity to buy water-pump generators, improved varieties, and inorganic fertilizers and adopt these CSA practices that are unaffordable to buy by ordinary smallholder farmers. Besides, these assets improve the ability to absorb the risks related to failure and the length of time in realizing CSAs. This is in line with the work of Wijk et al. (2020) that justifies the bigger size of farms increases the benefits of economies of farmers' scales and also furnish a way of product diversification. Farmers of only one farm package practice ($C_1F_0R_0I_0S_0$) that only contains crop management practices were less likely to implement the packages as farm size increased. The probable explanation would be these farmers prefer to rent out their large-sized farms for other users rather than practicing agriculture since the small package may not provide reasonable production in the face of harsh weather conditions and this is an existing experience by smallholder farmers in South Western Ethiopia.

Table 12: Estimates of marginal effects for determinants of CSA packages by MNL

Variables	C ₁ F ₀ R ₀ I ₀ S ₀	C ₁ F ₀ R ₁ I ₁ S ₀	C ₀ F ₀ R ₁ I ₁ S ₁	C ₁ F ₁ R ₁ I ₀ S ₀	C ₁ F ₀ R ₁ I ₀ S ₁	C ₁ F ₀ R ₁ I ₁ S ₁	C ₁ F ₁ R ₁ I ₀ S ₁	C ₁ F ₁ R ₁ I ₁ S ₁
	Dy/dx	Dy/dx	Dy/dx	Dy/dx	Dy/dx	Dy/dx	Dy/dx	Dy/dx
Socioeconomic factors								
Age of HH	-0.0018*	0.0006	0.0014	-0.0017	0.0017**	0.0015	0.0018	0.0000
Gender of HH	-0.0343	0.0054	0.0430	-0.0293	-0.0039	0.0040	-0.0041	0.0312**
Education years of HH	0.0014	0.0016	0.0022	-0.0305**	0.0018	0.0031	0.0018	0.0000
Size of HH	0.0077	-0.0005	-0.0030	-0.0328	0.0049	0.0002	0.0047	0.0003
Off-farm employment participation	-0.0314	0.0011	0.0523	-0.0429	-0.0217	-0.0261	-0.0156	0.0013
Farm size	-0.0269***	-0.0103	-0.01768**	-0.0216	0.0220*	0.0315*	0.0210***	0.0015**
Farm assets	0.0042	0.0008	-0.0054	0.0015***	0.0015	0.0003	0.0611***	0.0411*
Characteristics of farm								
Perception of land terrain	-0.0003	0.0066	-0.0213	0.0885	-0.0187	0.0051	-0.0166	0.0022
Perception of the severity of erosion	-0.0206	-0.0431**	0.0179	-0.0362	-0.0252**	0.0189	-0.0523***	0.0006
Perception of soil fertility	-0.0072	-0.0003	0.0206	0.1064***	-0.0215	-0.0023	-0.0152***	0.0005
Incidences								
Frequent floods	0.0371	-0.0277	-0.0340	0.0301	0.0220*	-0.0193	0.0213	0.0004
Hailstorms	0.0269	0.0051*	-0.0047	-0.0171	0.0284	0.0003	0.0182	0.0005
Insufficient rains	-0.0032	0.0007	-0.0186	0.517	-0.0422	0.0062	-0.0411	0.0003
Institutional factors								
Distance from farm to market	0.0001	-0.0002	-0.0006*	0.0022	-0.0005**	-0.0198	-0.0006**	0.0001
Membership in farmer's associations	0.0316	0.0265	-0.0215	0.1779**	0.0332	0.0058	0.0332**	0.0000
Contacts with extension agents	-0.0052	0.0031	0.0081	-0.0317***	0.0051	0.0018	0.0047**	0.0003*
Access to credit	-0.0482*	-0.0033	-0.0074	-0.1493**	0.0019	0.0427	0.0031***	0.0002

Number of observations = 384; Wald X2 (120) = 553.51, $p = 0.000$

C₀F₀R₀I₀S₀ is the reference category base in the MNL; HH is the household head

** Significant at 5% level

* Significant at 10% level

*** Significant at 1% level

Farmers' perception of soil erosion was negatively associated with the use of these packages: C₁F₀R₁I₁S₀, C₁F₀R₁I₀S₁, and C₁F₁R₁I₀S₁. The probability of using these packages declined by 4.3%, 2.5%, and 5.2%, respectively for farmers that considered their plots severely eroded. It looks like farmers are highly encouraged to undertake CSA practices on less eroded farms and vice versa. Practically, these farmers were not responsive to countering severe erosion impacts but were discouraged by severe erosion in implementing CSA technologies. A similar study conducted by Ali & Erenstein (2017) indicated a positive relationship with many soil conservation practices adoption with the consent that farmers were responsive to effects of soil degradation brought by soil erosion.

Farmers' perception of farmland soil fertility had a positive and significant influence on the usage of the C₁F₁R₁I₀S₀ package and a negative impact on the use of C₁F₁R₁I₀S₁. The use of C₁F₁R₁I₀S₀ and C₁F₁R₁I₀S₁ by farmers is likely to increase by 10.6% and get reduced by 1.5% respectively,

for farmers that consider their farmland is relatively fertile. This leads to the understanding that farmers who believe their farms are fertile likely opt to implement small package $C_1F_1R_1I_0S_0$, which is against the non-use of any package. This is a lean package that has insignificant soil replenishing effect. But those farmers who believe their farmland is less fertile preferably implement a $C_1F_1R_1I_0S_1$ package with more CSA practices included that play a soil fertility improvement role. Hasan et al. (2018) reported that the propensity for sustainable agricultural practices adoption such as improved maize is expected to be higher on plots with fertile soils because most improved varieties of maize demand expensive inorganic fertilizer application.

The choice of CSA packages is influenced by factors related to past experiences with extreme weather conditions. For example, frequent flood experiences in the past were more likely to use the $C_1F_0R_1I_0S_1$ package. The probability of using this package was increased by 2.2% for farmers with frequent flood experiences in the past. It is more likely that farmers opt to implement flood-related shocks response strategy to reduce soil degradation and maintain the fertility of the soil. On the other hand, (Arayal et al., 2020) argued that climate adaptation technologies adoption such as using drought-resistant varieties and crop rotation is negatively and significantly influenced by adverse conditions induced by flooding such as waterlogging and frost stress.

Previous experience with hailstorms was also positively related to the use of $C_1F_0R_1I_1S_0$ package. It was indicated that the likelihood of using this package improved by 0.51% for farmers who had past hailstorm experiences. Likewise, these farmers could be implementing a strategy responsive to this problem including farm risk reduction and supplementary income generating practices. A study conducted by Hussain et al. (2019) in contrarily reported that frequent hailstorms were the major source of production risks associated with climate change that discouraged production technologies adoption posing a threat to stable yield.

The use of CSA practices was negatively influenced by distance (measured by walking time) to the input-output market. An increase in the time elapsed to reach the market by 1 min declined the probability of using $C_0F_0R_1I_1S_1$, $C_1F_0R_1I_0S_1$, and $C_1F_1R_1I_0S_1$ by 0.06, 0.05, and 0.06%, respectively. The transaction costs associated with input purchase and output sale are increased as the distance to the market gets longer. Chavas et al. (2019) presented that distance can affect the accessibility of new technologies, credit institutions, and information, apart from access to the market, and thus confirms the negative association.

Farmers' membership in various associations/groups had a positive and significant impact on $C_1F_1R_1I_0S_0$ and $C_1F_1R_1I_0S_1$. With respect to the non-adopters, the probability of using these packages, as a result of being a member of farmers' associations, has increased by 17.7% and 3.3%, respectively. Farmer's associations are crucial channels through which extension agents and other service providers use to get farmers. In addition, field management practices such as terrace construction could be possibly achieved in mass mobilization using these channels as one option. Further, members of the associations exchange ideas, get connections for research output dissemination and handle farm demonstrations through this avenue. Kumar et al. (2019) reported that learning from peer experiences enhances the probability of adoption of technologies due to the reason that farmers put trust in more practical experiences shown by their peers since they share much in common.

The frequent contact with extension agents positively influenced the use of $C_1F_1R_1I_0S_1$ and $C_1F_1R_1I_1S_1$ but negatively affected the use of $C_1F_1R_1I_0S_0$ packages. Additional contact with extension agents annually increased the probability of using $C_1F_1R_1I_0S_1$ and $C_1F_1R_1I_1S_1$ by 0.47 and 0.03%, respectively but reduced the probability of using $C_1F_1R_1I_0S_0$ by 3.1%. This suggests that the adoption of larger packages by farmers is largely influenced by extension agents' contacts with farmers. It also highlights that the issue of climate change was included in information dissemination that promoted the use of many packages. Nevertheless, on the other hand, a reduced probability of using $C_1F_1R_1I_0S_0$ implies that extension agents' services had mixed roles. It looks evident that farmers using $C_1F_1R_1I_0S_0$ package with only crop, field management practices, and risk reduction practices only was skeptical about the information provided by the extension agents that it truly improves production, and decide to opt-out using any other package. This is consistent with the findings of the study in Kenya by Emmanuel et al. (2016) that described the involvement of extension agents in many more activities such as administering credit and delivering inputs, which pose questions of their skills impacting trust and finally declining implementation.

Access to credit had a positive and significant impact on the use of $C_1F_1R_1I_0S_1$ but a negative impact on the use of $C_1F_0R_0I_0S_0$ and $C_1F_1R_1I_0S_0$. The result depicted that farmers that received credit in the previous farming season were 0.31% more likely to use $C_1F_1R_1I_0S_1$. Access to credit enables farmers to meet costs involved in CSA technology implementation, especially high-priced ones such as the use of irrigation and improved livestock breeds present in this package containing a large package. Likewise, (Acclassato et al., 2021) discussed credit constraints that affect

investment in inorganic fertilizer and improve seed negatively, explaining that credit-constrained farmers are less likely to adopt CSA practices that require cash expenditures. Credit access reduced the probability of using $C_1F_0R_0I_0S_0$ and $C_1F_1R_1I_0S_0$ packages by 4.8% by 14.9%, respectively. A negative influence of access to credit to the use of $C_1F_0R_0I_0S_0$ and $C_1F_1R_1I_0S_0$ may suggest that these farmers prefer the credit access to be diverted to non-farm expenses such as medical and school fees, thus use of any package is unnecessary.

4.4.4 Average treatment effects for the adoption of CSA packages

Once the drivers of choice of CSA packages are determined in the first stage, the effect of treatments was determined in the second stage to evaluate the effect of these packages' use on household food security (Table 13). The ordinary least squares regression of per capita annual food expenditure, Household Food Insecurity Access Scale (HFIAS), and Household Food Consumption Score (HFCS) of households were estimated for every combination of CSA practices, considering the selection bias correction terms from the primary stage. Treatment effects, which are the most important part of this stage are discussed.

The per capita annual food expenditure measured the amount of dietary energy in (K/cals) through converting the food acquisition or consumption by matching individual foods with the food consumption table. Thus, a high per capita annual food expenditure results in higher dietary energy content, and correspondingly the level of food security is understood as food secure. HFIAS, with its nine occurrence questions, finally resulted in different severity levels (0-27) of food insecurity. The severity levels approaching zero is regarded as food secure, a value approaching 27 corresponds to severely food insecure and values ranging from 9 to 16 are regarded as moderately food insecure. Further, HFCS, with a frequency of consumption of diets over a seven-day period gives higher weights for nutritionally dense foods with a score classified as acceptable for nutritionally dense foods such as animal products, and other low dense foods such as tubers are regarded as poor and other meal types fall under moderate classification. Generally, a high calorific value, lower severity levels, and acceptable food consumption score are considered food secure and vice versa.

Table 13 presents the average adoption effects in terms of per capita annual food expenditure, HFIAS and HFCS under actual and counterfactual conditions. In Table 13, X_1 represents the treated category (adopters) and X_2 represents the untreated (non-adopters), β_1 denotes treated

characteristics (adoption state) and β_2 representing untreated characteristics (non-adoption state). The difference in food security status as a result of a specified package is regarded as the level effect. The result of the difference between treated with treatment features and untreated with untreated features ($\beta_1 X_1$) – ($\beta_2 X_2$) is termed the impact. Except for users of C₁F₀R₁I₀S₁, C₁F₁R₁I₁S₀, and C₁F₁R₁I₁S₁, all the rest employing other packages would be better off in the counterfactual scenarios (non-adopters) signifying the availability other better possibilities. Apart from C₁F₀R₁I₁S₁, all other packages that included farm risk reductions and supplementary income generation practices had a positive impact on household welfare. This implies that farmers need to manage their farm risks and diversify income-generating practices to improve the food security status in the face of uncertain climate change events.

Table 13: Impact of use and non-use of CSA packages on food security estimated under the three parameters by ESR

Package		Per capita annual food expenditure (PCFE)			HFIAS			HFCS		
		Treated (β_1)	Untreated (β_2)	Impact/returns	Treated (β_1)	Untreated (β_2)	Impact/returns	Treated (β_1)	Untreated (β_2)	Impact/returns
C ₁ F ₀ R ₀ I ₀ S ₀	Treated(X_1)	0.54(2.10)	0.59(0.74)	-0.04	21.0(0.13)	24.1(0.34)	-3.14	45.2(1.54)	46.4(0.98)	-0.42
	Untreated(X_2)	0.59(1.92)	0.64(0.48)	-0.05	23.14(0.71)	24.51(0.49)	-1.37	53.1(2.14)	63.2(0.75)	-13.44
	Level effects	-0.05	-0.15*	-0.09	-0.01	-0.16	-5.16	-7.90	-16.8***	-16.85
C ₁ F ₀ R ₁ I ₁ S ₀	Treated	0.98(1.96)	0.72(3.17)	0.26	16.1(0.22)	16.9(0.42)	-0.73	66.7(7.56)	57.9(2.62)	8.17
	Untreated	0.62(3.14)	0.81(0.17)	-0.19	18.2(0.09)	18.6(0.11)	3.12	64.4(3.94)	64.7(0.81)	-0.47
	Level effects	0.36	-0.09	-0.71	-2.10	-2.3	1.91	2.30	-6.8***	2.7
C ₀ F ₀ R ₁ I ₁ S ₁	Treated	0.35(3.4)	0.31(1.8)	0.04	20.1(0.51)	21.4(0.66)	-0.25	62.1(3.45)	59.2(0.94)	-17.26
	Untreated	0.29(1.9)	0.27(0.8)	0.02	21.4(0.07)	22.3(0.07)	-0.19	58.1(2.42)	66.4(1.02)	-5.36
	Level effects	0.06	0.04	0.06	-1.3	-2.5	-0.12	4.00	-7.2	-2.81
C ₁ F ₁ R ₁ I ₀ S ₀	Treated	1.10(0.87)	0.99(0.12)	0.11	13.2(0.06)	12.9(0.12)	0.46	56.8(1.08)	66.7(1.04)	-11.04
	Untreated	1.21(0.99)	1.13(0.04)	0.04	11.1(0.07)	10.7(0.07)	0.12	59.9(0.99)	69.17(0.97)	-8.12
	Level effects	-0.11	-0.14	0.15	2.1	2.2	0.58	-3.20**	-2.4	-14.61
C ₁ F ₀ R ₁ I ₀ S ₁	Treated	1.11(0.14)	1.09(1.99)	0.02	10.8(0.05)	9.1(0.09)	0.32	56.2(1.04)	64.9(1.07)	-10.43
	Untreated	0.99(0.72)	0.87(2.14)	0.19	8.4(0.11)	7.8(0.13)	0.16	59.9(1.99)	69.0(0.97)	-8.32
	Level effects	0.12	0.22*	0.22	1.6*	2.7*	0.48	-3.70**	-4.10***	-11.51
C ₁ F ₀ R ₁ I ₁ S ₁	Treated	1.35(1.9)	1.28(2.5)	0.07	5.16(0.26)	6.12(0.07)	1.12	64.0(2.55)	68.1(0.90)	2.12
	Untreated	1.22(2.1)	1.18(0.5)	0.04	7.93(0.43)	8.08(0.19)	1.56	63.8(2.01)	64.2(0.87)	1.94
	Level effects	0.13**	0.1	0.14	2.17*	2.71	2.68	0.20	3.90***	4.06
C ₁ F ₁ R ₁ I ₀ S ₁	Treated	1.42(1.02)	1.19(0.17)	0.23	5.07(0.15)	4.17(0.13)	0.9	75.1(1.04)	63.6(0.84)	10.59
	Untreated	1.01(0.77)	0.98(1.31)	0.03	6.31(0.09)	5.12(0.17)	1.19	75.4(1.30)	61.4(0.92)	12.13
	Level effects	0.21*	0.21	0.26	1.24**	0.95	2.19	-0.30	2.20*	22.72
C ₁ F ₁ R ₁ I ₁ S ₁	Treated	1.54(0.91)	1.21(2.7)	0.33	0.11(0.01)	0.01(0.07)	0.10	82.1(1.17)	69.0(0.91)	17.2
	Untreated	1.37(0.77)	1.08(1.5)	0.29	1.31(0.06)	1.22(0.02)	0.09	78.0(1.21)	65.1(0.87)	15.1
	Level effects	0.27***	0.13**	0.72	1.20**	1.33***	0.19	4.10***	3.90***	32.3
Pairwise correlation										
	PCAE	HFIAS	HFCS							
PCAE	1									
HFIAS	-0.67**	1								
HFCS	0.88**	-0.71**	1							

Standard errors are in parenthesis. C crop management, F Field management, and climate change mitigation, R risk reduction, I supplementary income, S soil and water conservation. PCAE per capita annual expenditure, HFIAS household food insecurity access scale, HFCS household food consumption score

For bigger packages (C₁F₀R₁I₀S₁, C₁F₁R₁I₁S₀, and C₁F₁R₁I₁S₁), all adopters were food secure compared to their counterparts that did not adopt CSAs in real scenarios. Based on these findings, a complete package with crop management practices, field management, and climate change mitigation practices, farm risk reduction practices, supplementary income generating practices, and soil and water conservation practices (C₁F₁R₁I₁S₁) had the highest overall effect of kcal, 0.19 level of severity, and 32.3 scores on the status of food security of farmers estimated using per capita annual food expenditure, HFIAS, and HFCS, respectively. This implies that farmers using this package were 41.2%, 39.8%, and 12.1% more food secure compared to their counterparts who were using none of the practices included under this package. This wide-ranging package addresses a bigger spectrum of both field, income, mitigation, and soil conditions while also climate change mitigation, soil degradation mitigation for stabilizing productivity, and income diversification. In a general context, the overall finding is that non-adopters of this (C₁F₁R₁I₁S₁) package would suffer from food insecurity. Farmers using this package, in addition to productivity improvement (food security), also play a major role in mitigation and farmers' resilience to adverse climate change impacts.

4.5 Policy implications

The findings of this study have fundamental policy implications for enhancing CSA adoption and its intensity among Geshy watershed beneficiary farmers. As evidenced in the result section, first and foremost, in terms of adoption, the CSA practices are complimentary. This informs that the implementation of CSA and the agricultural policy must recognize the complementarity among CSA practices so as to intensify their adoption among Geshy smallholder farmers and expand CSA technologies in other parts of the nation. Secondly, policy makers should take into account institutional, household socioeconomic, and resource related factors that influence CSA adoption positively. Frequent and regular extension and advisory service provision to smallholder farmers needs to be prioritized. This enables farmers adopt more CSA practices. In addition, disseminating information and creating awareness about the benefits of CSA practices adoption and the potential impacts of climate change using different media outlets helps farmers make informed decisions on CSA adoption and, thus, coping with climate change adverse effects. Few CSA practices, for instance soil and water conservation practices are unpopular among farmers in the Geshy watershed. Hence, high incentive payments are required for scaling-up of its adoption. In Ethiopia, one of the important wealth that has an intergenerational impact on agricultural technology

adoption, is land. The finding of this study reveal that farmers with relatively bigger land sizes are more likely to adopt CSA practices. And thus, agricultural policies should focus on controlling rental markets of agricultural lands, which helps diligent smallholder farmers acquire more land.

4.6 Conclusion

This paper evaluated the impact of climate-smart agriculture on food security of smallholder farmers in the tropical moist montane ecosystem of South Western Ethiopia. Climate-smart agriculture is currently promoted as an effective approach to improving food security and livelihood situations globally, especially in resource-poor developing countries including Ethiopia. It does this by sustainably increasing agricultural productivity, improving household resilience, and reducing greenhouse gas emissions.

The findings show that smallholder farmers adopting more than one CSA practice experience better food security and livelihood situations as compared to non-adopters. The bigger package that consisted of crop management, field management, climate change mitigation, risk reduction, income generation, and soil and water conservation practices (C₁F₁R₁I₁S₁) had the highest impact on household food security as compared to the non-adopters (C₀F₀R₀I₀S₀). Adopters of this package were 41.2% more food secure in terms of per capita annual food expenditure, 39.8 percent in terms of Household Food Insecurity Access Scale (HFIAS), and 12.1 percent in terms of Household Food Consumption Score (HFCS) than the non-adopters. The adoption of this package was further positively influenced by farm size, gender, and productive farm asset values. This package is covering a wide spectrum and comprehensive field, soil, income, climate change mitigation conditions for reducing soil degradation, diversifying income sources, climate change mitigation, and production stability. Accordingly, for farmers to get the maximum benefit from CSAs, they have to incorporate all CSAs as much as possible. The results depicted that the likelihood of using this package was influenced positively by farm size, gender, and farm assets. This package was more likely on larger self-owned pieces of plots, and male-headed households with greater farm assets. Thus, if CSAs are used in combination and to a larger extent, they have the potential to alleviate food insecurity.

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CHAPTER 5: ANALYZING THE ROLE OF CLIMATE-SMART
AGRICULTURE ON HOUSEHOLD WELFARE IN A MIXED FARMING
SYSTEM OF GESHY WATERSHED, SOUTHWEST ETHIOPIA

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ANALYZING THE ROLE OF CLIMATE-SMART AGRICULTURE ON HOUSEHOLD WELFARE IN A MIXED FARMING SYSTEM OF GESHY WATERSHED, SOUTHWEST ETHIOPIA

5.1 Abstract

This study assess the impact of climate-smart agriculture (CSA) technology adoption on the welfare status of households in a subsistence mixed farming system in the Geshy watershed, South West Ethiopia. Due to the changing climate, characterized by changes in patterns of rainfall and rising temperature, the livelihoods of smallholder rural farmers are highly threatened. For the households that are highly dependent on rain-fed agriculture, coping mechanisms, proper adaptation, and mitigation measures are hence important steps to improve household incomes and livelihoods. CSA offers this opportunity. A cross-sectional survey data, collected from 384 households, was used to analyze the impact of CSA on food security and household income. The research model used in this study was the endogenous switching regression model, which controls unobserved heterogeneity and selection bias, a method used commonly in analyzing adoption impacts. The study revealed that various socioeconomic and agricultural factors influencing food security and CSA adoption. The econometric analysis result showed that the variables that had a significant impact on farmers' decisions for CSA adoption were soil fertility status, distance to market, asset, and livestock ownership. The average values of the treatment effects of the untreated (ATU) and treated (ATT) result in a positive and significant impact on farmers' welfare. Factors such as household head education, size of labor, livestock size, and asset index significantly affected household income. The level of education, the size of irrigable land, and livestock size influenced food security. This study concludes that households that adopted more CSA practices experience better welfare. Access to inputs, encouraging investments in assets, irrigation, and livestock production, providing incentives to input dealers for rural areas decentralization, and access to weather forecasts improvements are all-important to exploit the full potential of climate-smart agriculture technologies as policy recommendations.

Keywords: Climate-smart agriculture (CSA), Welfare, Food security, Household income, Endogenous switching regression model, Geshy watershed

5.2 Introduction

The agriculture sector remains to play a fundamental role in the economic growth and development of Ethiopia. It contributes 35.8% of gross domestic product (GDP), 90% of exports, 72.7% of employment, and 70% of raw material industrial requirements (Ayele et al., 2021; Caravaggio et al., 2021; Yigezu 2021a). The nation is gifted with abundant agricultural resources, soil and water for high-value crop production of field cash crops such as sesame, coffee, and cotton, as well as cereal food crops such as wheat, maize, barley, legumes, and vegetables. The country is well known for its *teff* (*Eragrostis tef*) production as a staple food for the majority of its population. The country, nowadays, is putting all the necessary efforts to substitute wheat imports with domestic production. In 2020 alone, Ethiopia imported wheat by \$320 million, becoming the world's 39th biggest wheat importer (Erchafo et al., 2021). Ethiopia's smallholder farmers cultivate more than 90% of the total cropland and provide more than 90% of agricultural output (Zerssa et al., 2021). The productivity of crops is influenced by limited technology use such as improved varieties and livestock productivity is affected by unreliable availability and low-quality forage in dry seasons (Headey et al., 2014). Additionally, farmers experience under-developed markets that constrain their financial returns, because they are characterized by low output prices and high input costs, coupled with climate changes and recurrent drought event effects (Aliyi et al., 2021). Climate change and extremes such as erratic rainfall, frequent droughts, and temperature extremes create favorable conditions for pest outbreaks, disease, insects (e.g. armyworms and locusts), which resulted in declined crop yield (Mihiretu et al., 2021). Studies confirmed the impact of climate change and extremes on food and forage production will become more severe (Escarcha et al., 2018; Rettie et al., 2022; Rojas-Downing et al., 2017). Models predict that the climate change in sub-Saharan Africa is greater than the global average leading to extreme events such as floods and droughts, thereby adversely affecting smallholder farmers that are heavily relying on rain-fed agriculture for their livelihoods (Etana et al., 2020; Tofu et al., 2022). Livestock and crop productivity have also been highly affected by disease and pest incidence (Tadesse et al., 2021). Progressive yield reduction over succeeding agricultural seasons will negatively influence household food security usually relying on staple food production of their own (Agidew & Singh, 2018; Dijk et al., 2020). The unpredictable one-time high-intensity rainfall pattern raises a serious threat to farmers, as water is the basic resource that is becoming a determinant factor under such

circumstances. Accordingly, the government of Ethiopia promoted climate-smart agriculture (CSA) by developing a national road map in 2020 (Eshete et al., 2020).

5.3 Significance of CSA in mixed smallholder farming systems

One of the important routes toward improving the welfare of smallholder farming communities in developing nations, experiencing adverse climate change impacts, is CSA adoption. (Mujeyi et al., 2021; Ogada et al., 2020). CSA can support farmers achieve the growing food demand. Generally, CSA contributed to food security, poverty reduction, and economic development (Habtewold, 2021; Wekesa et al., 2018). Literature suggests that improved agricultural productivity can enhance household welfare by increasing income (Cleves et al., 2022; IPCC, 2014). There is empirical evidence on grain productivity and welfare improvement on CSA-based technologies of crop and livestock from on-farm and on-station trials. For instance, drought-tolerant maize varieties adoption improved the yield of maize among adopters by 13.3% and the exposure to downside risk by 81% (Wekesa et al., 2018). Further, diversified crop production increased the yield of spring wheat in no-tillage by up to 30% and by 13% under plowing relative to monoculture (Jalli et al., 2021).

Soil and water management CSA practices reduce water losses from runoff and improve water infiltration (mulching), protect the soil (minimum tillage), improve soil fertility (intercropping), manure use and rotation, and reduce evaporation (Du et al., 2022; Ehabu et al., 2022). In addition, use of CSA agronomic practices, using improved varieties of improved legumes and drought-tolerant maize significantly improve crop yields. The recent innovations in CSA, are, therefore, built in addition to the best water and soil management and best agronomic practices. Several research findings examined the effect of CSA on household welfare and revealed both direct and indirect results. Some of the direct results include crop and livestock productivity improvement, and declined variable costs, while the indirect results include increased household income, improved food security through enhanced availability of staple crops in the market and at the level of household (Jalli et al., 2021; Mujeyi et al., 2021), and high demand for farm labor, that results in better wages for agricultural returns (Ogada et al., 2020; Sain et al., 2017). Researchers use various ways of studying the CSA impact on food security and other livelihood outcomes. Some use the endogenous regression model (ESR) by employing household food security measurement tools such as Household Dietary Diversity (HDD) and Household Food Consumption Score

(HFCS) as food security proxies. Others use composite indexes that employ weighting and normalization methods such as Food Insecurity Multidimensional Index which incorporates the four food security dimensions, i.e., availability, Access, utilization, and stability (Mujeyi et al., 2021; Sisha, 2020). The study by Wekesa et al. (2018) came up with evidence that farmers using multiple CSA packages containing crop management, risk reduction practices, field management practices, and specific soil management practices showed 56.83% more food secure in terms of HFCS compared to their counterpart non-adopters. A study by Ogada et al. (2020) indicated that CSA adoption such as using improved varieties increased household income by 83%, which in turn enhanced household asset accumulation.

The CSA technologies are hence very important for countries like Ethiopia, which are regarded as climate change ‘hotspots’ due to the increased chance of occurrences of extreme events such as flooding and drought (Teshome & Zhang, 2019). Therefore, the the purpose of this study was to examine mixed farming practices (crop production, forestry, and livestock production) effect on the welfare of households in subsistence farming systems.

5.4 Methodology

5.4.1 Model specification

Earlier adoption studies and the empirical evidence on agricultural technologies suggested the choice of variables adopted in the Endogenous Switching Regression Model. These technology adoption drivers of CSA include household characteristics (gender, age, level of education, family labor and household size), ownership of assets, technical and institutional factors (groups/farmers organization membership, access to extension services, credit access, training on CSA, ownership of assets such as television, radio, and mobile phones) perceived benefits (increased income, enhanced productivity, reduced cash inputs, reduced risk of livestock and crop loss, and food security), and farm characteristics (land tenure, soil fertility, and slope) (Branca & Perelli, 2020; Pagliacci et al., 2020).

To enhance farmers’ desire towards adopting CSA and make the required contribution in the effort to improve household welfare, it is imperative to be aware of the obstacles and drivers that affect farmers’ choices and decisions and understand variables that influence welfare variables, i.e., household food security and income (Mujeyi et al., 2021). Smallholder farmers are considered to be heterogeneous agents, and the tendency to decide to adopt new CSA technologies is influenced

by the availability of technology, resources, and information (Kangogo et al., 2021). Households find investments in new technologies attractive if they found the benefits significantly offset the cost (Mujeyi et al., 2021). Thus, the decision of adopting a certain CSA technology can be viewed through the lens of constrained optimization, where the choice of households choose the technology depends on its availability, affordability, and its beneficial use (Khatri-Chhetri et al., 2019). The expected benefits are determined by observable and non-observable factors. An adopter of a CSA is therefore a certain household that adopts a minimum of one CSA from a list of available eighteen practices (small-scale irrigation, alley cropping, use of organic fertilizer, use of improved varieties of crops, use of efficient inorganic fertilizer, planting trees for windbreak and shelter for crops, use of mulching, changing planting dates, cover crop practices, crop rotation using legumes, improved animal husbandry, poultry farming, use of terraces, apiculture, feed improvement, sheep fattening, use of grasses, and use of briquettes). It is so because farmers are considered to be rational, and as long, they adopt technologies that satisfy their objectives and address limitations they encounter during production.

To examine the effect of CSA technologies on selected household welfare, two indices were used, i.e., food security and average household income (Mujeyi et al., 2021; Wossen et al., 2019). Welfare is defined as the total utility derived from all the goods and services consumed (Wossen et al., 2019). Various outcome indicators are used by researchers to measure welfare that includes consumption, income, expenditure, poverty(poverty headcount and poverty gap), asset-based wealth indices, and food security (Mayfour & Hruschka, 2022; Wijk et al., 2020). The food and Agricultural Organization of the United Nations (FAO) defined food security as a condition when all people at all times have economic and physical access to adequate, safe, and nutritional foods to satisfy their dietary needs for an active and healthy life (FAO, 2008). Various proxies of indicators of food security have been used to capture the four dimensions (availability, access, utilization, and stability), including food insecurity scores, Dietary Diversity Scores, hunger scale, food utilization (anthropometry as a proxy i.e., weight-for-height, body mass index (BMI) for age, height-for-age, and weight for age (Bilbeisi et al., 2022; Nicholson et al., 2021; Sisha, 2020). For this study, one of the indicators of food security used was the Household Food Consumption Score (HFCS). The HFCS is a score computed using the consumption frequency of various groups of foods consumed during the 7 days by a household before the survey. Standard weights are attached for each food group that comprises the score of food consumption and by summing up these

weights, the food security level will fall into either of the three categories (poor, borderline, acceptable) (Fite et al., 2022).

Climate-smart technologies adoption of CSA can improve livestock and crop production, and thus the household can generate income by marketing the surplus in addition to the availability of food. Some CSA practices are labor-saving and help provide labor for other off-farm practices that can generate additional income for the household (Autio et al., 2021). The income of the household was the combination of incomes from on-farm (crop and livestock) and off-farm, as well as other income sources (gifts, in-kind transfers, and remittances).

Adoption has been measured, in various studies, as a continuous treatment (the Propensity score and Tobit methods) or as a binary treatment (the Logit and Probit models) (Awotide et al., 2016; Jones-Garcia & Krishna, 2021; Ruzzante et al., 2021; Yigezu et al., 2018). For the purpose of this study, the relationship between the outcome variables (food security and household income) and the exogenous variables was examined using the Endogenous Switching Regression (ESR) model. The study employed the switching of selection bias, which results from those that are not treated, due to the fact other than treatment status. The Switching Regression Model is a modified classical Heckman Selection model. The ESR has two simultaneously estimated equations in STATA using the outcome and selection equations.

Equation selection

Two choices are available to farmers, either to adopt or not to adopt CSA. The relationship between these two alternatives is determined by the Probit model in the following Equation (21):

$$A_i^* = \beta Z_i + u_i \quad (21)$$

$A = 1$ if $A_i^* > 0$; $A = 0$ if otherwise, i.e., $A_i^* \leq 0$.

A_i^* is the dependent latent binary (dichotomous) variable for CSA adoption

β is the vector of unknown parameters

Z_i is the vector of observable characteristics (farm, farmer, etc) influencing the CSA adoption decision.

U_i is the error term that captures the unobservable characteristics

Outcome equation

Using ESR, the outcome variables (income and food security status) are computed as follows in Equation (22) and (23):

$$\text{Regime 1 (adoption of CSA): } Y_{1i} = X_{1i}B_1 + \varepsilon_{1i} \quad \text{if } A_i = 1 \quad (22)$$

$$\text{Regime 2 (Non-adoption of CSA): } Y_{2i} = X_{2i}B_2 + \varepsilon_{2i} \quad \text{if } A_i = 0 \quad (23)$$

Where Y_1 and Y_2 levels of outcomes (food security (HFCS) or gross household income) for adopters and non-adopters, respectively, and X_1 and X_2 are vectors of factors that influence food security

Equations 1, 2, and 3 are assumed to have a triumvirate normal distribution, with a covariance matrix and a zero mean, which is expressed in Equation (24):

$$\text{Cov}(e_{1i}, e_{2i}, u_i) = \begin{pmatrix} \sigma^2_{e^2} & \cdot & \sigma_{e2u} \\ \cdot & \sigma^1_{e^1} & \sigma_{e1u} \\ \cdot & \cdot & \sigma^2_u \end{pmatrix}, \quad (24)$$

Where σ^2_u = variance of errors term in the selection equation
 $\sigma^2_{e^1}$ and $\sigma^2_{e^2}$ error term variances in the outcome equation
 σ_{e1u} and σ_{e2u} = covariance of u_i, e_{1i}, e_{2i} .

The expected outcome (food security and income) of the household that adopted the CSA technology (Eq. 22) and that did not (Eq. 23), are compared by the ESR model. It is also used to investigate the expected income and food security in the cases of counterfactual analysis (Eq. 28) that the CSA non-adopters did adopt and the CSA adopters did not adopt (Eq. 27). It is also more likely that some unobserved factors that influence CSA adoption may also affect the income or food security (outcome variables). Thus, in the outcome and selection equations, the error terms can be correlated (Eq. 21, 22, and 23). The estimation of these three equations was done simultaneously to solve these problems. This analytical framework is hence used to estimate the treated and untreated mean treatment effects, i.e., the ATT and ATU, respectively using the following equations:

For adopters of CSA with adoption:

$$E(Y_{i1}|A) = X_{i1}\beta_1 + \sigma_{1\varepsilon}\lambda_{i1} \quad (25)$$

For non-adopters without adoption:

$$E(Y_{i2}|A) = X_{i2}\beta_2 + \sigma_{2\varepsilon}\lambda_{i2} \quad (26)$$

For counterfactuals:

CSA adopters, had they not adopted:

$$E(Y_{i2}|A = 1, x) = X_{i1}\beta_2 + \sigma_{2\varepsilon}\lambda_{i1} \quad (27)$$

CSA non-adopters, had they decided to adopt:

$$E(Y_{i1}|A = 0, x) = X_{i2}\beta_1 + \sigma_{1\varepsilon}\lambda_{i2} \quad (28)$$

The actual expectations are given by Eqs. 4 and 5, from data observation, while Eqs. 6 and 7 provide the counterfactual expected outcomes. The measure of change in food security outcome (food security or income) is given by the mean treatment effect (ATT):

For average treatment effects on adopters:

$$\begin{aligned} ATT &= E(Y_{i1}|A = 1, x) - E(Y_{i2}|A = 1, x) \\ &= X_{i1}(\beta_1 - \beta_2) + \lambda_{i1}(\sigma_{1\varepsilon} - \sigma_{2\varepsilon}) \end{aligned} \quad (25)$$

For average treatment effects on non-adopters:

$$\begin{aligned} ATU &= E(Y_{i1}|A = 0, x) - E(Y_{i2}|A = 0, x) \\ &= X_{i2}(\beta_1 - \beta_2) + \lambda_{i2}(\sigma_{1\varepsilon} - \sigma_{2\varepsilon}) \end{aligned} \quad (26)$$

The unobserved factors are adjusted by λ_{i1} and λ_{i2} for ATT and ATU, respectively.

With observational data (as opposed to experimental data), the ESR model is used to address issues of self-selection and the estimation of treatment effects, when there is a non-random allocation of subjects to control and treatment groups (Aravindakshan et al., 2018).

In reviewing various literature, the important food security determinants include the age of the household head, education level, availability of input, adoption of technology, farm size, land quality, input price, food expenditure, gender, size of household, credit access, level of household income, and access to sanitation and safe water (Habtewold, 2021; Mujeyi et al., 2021; Ogada et al., 2020; Wekesa et al., 2018). The model formation for selection and outcome was based on the hypothesis that was justified by reviewing the literature. The decision of farmers to reject or adopt CSA is affected by the simultaneous effect of many factors associated with farmers' objectives, asset ownership, biophysical characteristics of locations, constraints, and characteristics, and the attributes of the technology (Amare & Simane, 2017; Musafiri et al., 2022c; Waaswa et al., 2021).

One of the factors hypothesized as a factor creating or minimizing confidence in new technology adoption was the farmers' age. Conservative and resistance to adopting new technologies may occur from more experienced farmers. Additionally, these farmers may be willing to try new technologies if they previously have tried and obtained a certain positive result. This variable can either positively or negatively affect decision of farmers' to adopt CSA technology.

5.5 Results and discussion

5.5.1 Summary of the descriptive variables used in the estimation

The descriptive statistics of the data for the important variables included in the estimation of the ESR model are presented in Table 14. The t-test was used to see the variation between adopters and non-adopters of CSA technologies for relevant continuous variables (i.e., household FCS, log income, farming experience, education, labor size, household size, distance to input, TLU, frequency of contact with extension agents, etc.), while the difference between the two groups for categorical binary variables (i.e., asset ownership, CSA awareness, credit access, safe water and sanitation access, access to the weather forecast, the status of soil fertility, and group membership, etc.) designated using Chi-square test. Soil fertility was identified

Table 14: Summary statistics and variables used in the ESR

Variable	Adopter		Non-adopter		Sum		Test statistic t-test
	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev	
HH food security (FCS)	82.11	69.35	45.25	39.4	77.45	65.75	1.65 ^b
Annual HH income (ETB)	32500	29500	7900	5100	25500	18700	1.72
HH age (years)	37.45	13.25	41.25	17.55	40.5	27.25	-0.52
HH size (number)	4.55	2.71	4.25	2.55	4.48	3.19	-0.73
HH farm experience (years)	25.25	20.55	24.75	21.23	25.50	20.50	-0.96
HH labour size (number)	3.45	1.97	3.25	2.01	3.15	2.73	-0.64
Soil fertility (1=fertile, 0=otherwise)	0.65	0.33	0.25	0.31	0.44	0.34	1.9
Arable land size (acres)	1.75	1.5	0.5	0.5	1.5	1.25	-1.35
TLU (number)	3.25	1.75	0.75	0.55	2.55	1.9	-1.18 ^c
Distance input market (Km)	30	27.1	21	18	25	20	-1.55
Distance output market (Km)	120	401	25	13	77	120	-0.89
Group membership (1 = yes, 0 = otherwise)	0.81	0.42	0.68	0.51	0.88	0.72	0.63
Contact with extension agents (number)	16.1	11.7	12.5	9.1	15.3	7.3	-0.79
Access to weather forecast (1 = yes, 0 = no)	0.55	0.37	0.31	0.4	0.56	0.38	5.32 ^b
CSA awareness (1 = yes, 0 = no)	0.41	0.12	0.39	0.11	0.40	0.22	0.01
Access to credit (1 = yes, 0 = no)	0.18	0.29	0.17	0.27	0.18	0.38	0.01
Income from crops (ETB)	11500	7200	2100	1500	9400	3400	0.02
Income from irrigation (ETB)	10000	2500	1800	950	7500	3800	10.03 ^a
Income from livestock (ETB)	6000	3050	1500	390	4000	2500	-0.88
Off-farm income (ETB)	5000	3023	2500	1900	4800	811	-0.91
Safe water access (1 = yes, 0 = no)	0.79	0.29	0.63	0.57	0.81	0.42	10.99 ^a
Sanitation access (1 = yes, 0 = no)	0.91	0.23	0.81	0.51	0.83	0.33	5.91 ^b
Asset index	7.64	3.25	6.94	3.92	7.66	3.45	-0.91

HH = household; ETB = Ethiopian Birr

^{a b c} = A significant level of 1%, 5%, and 10%, respectively

from the farm onsite, as the process of identification was supported by the enumerator to the household head during the survey.

The results revealed significant ($P < 0.05$) difference between non-adopters and adopters for variables such as household food security, livestock income share, income from irrigation, access to the weather forecast, access to water and sanitation, and total livestock unit (Table 1). The status of food security of households, measured by FCS, of adopters of CSA, significantly improved by about 45% as compared to non-adopters. This could likely be due to the productivity increase as a result of the CSA adoption. This is supported by similar studies conducted by (Abegunde et al., 2022; Autio et al., 2021; Kangogo et al., 2021), which indicated that smallholder farmers, adopting multiple CSA technologies, showed their productivity increased, were resilient to adverse effects, and contribute their share in climate change mitigation efforts. Farmers who are CSA adopters possess relatively significantly higher herd size, better access to weather information, earn significantly higher income from irrigation, and access to sanitation and safe water, as compared to non-adopters.

5.5.2 Switching regression analysis results

The result of the selection equation of the first stage analysis (CSA adoption), revealed that the factors such as distance to inputs and output markets, soil fertility status, and ownership of assets significantly predicted CSA adoption in the mixed farming system (Tables 15, 16). A unit increase in TLU and distance in the output market increase the likelihood of CSA adoption by 0.35, and 0.004, respectively. In smallholder farmers, owning large livestock numbers is considered storage of wealth, and households that own them are financially less constrained. This livestock can be sold at any time and able to purchase any farm input necessary for new technologies. This is supported by multiple studies conducted by Kebebe, (2019); Mathewos et al. (2021) and Ogada et al. (2020) that described livestock production as a key area that plays a major role in rural livelihoods through providing income and employment. These studies used different models but the results were found pretty comparable. In addition, a decrease in odds of adoption of CSA by 0.006 was recorded for a unit increase in distance to the input market. This finding is substantiated by studies conducted by (Kangogo et al., 2021; Mujeyi et al., 2021; Pagliacci et al., 2020; Wekesa et al., 2018) that showed a significant relationship between distance to input market and CSA adoption. It is justified that longer distances incur high transaction costs due to corresponding high transportation costs. Tables 2, and 3 present the ESR model result.

The second set of outcome equations from the ESR (i.e., household income and food security) analyzed the relevant factors that affect these outcome variables with respect to CSA adoption. The result revealed that smallholder farmers and market factors, as well as farm characteristics affected household welfare significantly. Tables 15, and 16 indicated that the level of education of the head of the household, size of cultivable land, labor size, the TLU, and asset index were the major factors that significantly predicted household income. Commonly, education was found out as having a significant impact on household income. This is supplemented by (Mujeyi et al., 2021), as more educated households can engage in better yield-enhancing CSA technology adoption activities, which in turn creates better conditions for sending as many products as possible to the market. Education promotes the ability of farmers to make sound decisions on future investments through managing their profitability. A larger size in labor, which is the abundantly available resource, also contributes to income increase through operating the farm operations, which improves productivity and some household members can engage themselves in other non-farm economic activities thereby improving the income of households. TLU had a positive and significant effect on the income of households. Livestock is indeed one of the fundamental savings methods in rural households that can be liquidated easily to bridge income gaps that may arise from within the household (Chen et al., 2021). Ownership of assets also had a positive impact on household income. This calls the farmers' attention to invest in productive agricultural assets.

The food security level of households was affected by factors such as small-scale irrigation, the TLU, education of household heads, and access to safe water and sanitation. Small-scale irrigation practices had positively and significantly affected the food security status of smallholder farmers. This is substantiated by a study conducted in Ethiopia by Jambo et al. (2021), which revealed that participation in small-scale irrigation practices increased the daily intake of calories of users by 643.76 kcal as compared to non-user households. The finding further highlighted that irrigation had a positive impact on crop production, consumption, and revenue generation. Total livestock units and education have also a positive and significant impact on the status of food security of smallholder farmers. These findings concur with other studies in the literature. A study in Western Ethiopia by (Kebebe, 2019) revealed that the status of household food security of smallholder farmers was influenced by the household heads education and ownership of livestock. Another similar study in Northern Ethiopia also found a positive and significant relationship between education and food security and TLU and food security (Endale et al., 2014; Hadush, 2018).

Table 15: Results of food security ESR model

Variables	Selection equation		Outcome equation (Food security)			
	(CSA adoption)		Adopter		Non-adopter	
	Coefficient	Robust Std, Err	Coefficient	Robust Std, Err	Coefficient	Robust Std, Err
Education	-0.06	0.06	0.07 ^b	0.18	0.05	0.03
HH size			0.17	0.43	0.02	0.04
Cultivable land size	0.11	0.09	0.103 ^b	0.088	-0.02	0.04
Extension agent contact	-0.03	0.04	-0.05	0.50	-0.002	0.03
Distance to output market	0.004 ^b	0.003	0.22	0.22	-4.6	-0.03
Off-farm income			0.002	0.004	0.00	0.00
TLU	0.26 ^b	0.20	0.30 ^b	0.19	0.07	0.03
Access to safe water and sanitation			0.33 ^b	0.18	-0.58	1.43
Distance to input market	-0.006 ^b	0.002				
Small-scale irrigation	0.61	0.42	0.89 ^a	0.73	0.01	1.41
HH age	-0.02	0.03				
HH farm experience	0.03	0.002				
Group membership	-0.34	0.64				
Weather forecast access	0.73	0.69				
Asset ownership	0.77	0.81				
Soil fertility	0.81 ^a	0.51				
Access to credit	-0.18	0.47				

^{a, b, c} = a significant level of 1%, 5% and 10%, respectively

Households with higher education levels can transfer information on new innovations such as CSA, and they can adopt yield-improving packages quickly that ultimately improve food security. Studies from eastern African countries also showed food insecurity to be correlated with low levels of education (Gebre & Rahut, 2021). This finding also supports the results of (Wekesa et al., 2018) who documented that higher education level at the household level could lead to a better understanding of new technologies. Education improves farmers' reasoning capability and enables them to have enhanced awareness of new technologies. It also enables smallholder farmers in reading and acquires knowledge on agricultural information, education, and communication (IEC).

Table 16: Results of income of household using ESR model

Variables	Selection equation		Outcome equation (Income)			
	(CSA adoption)		Adopter		Non-adopter	
	Coefficient	Robust Std, Err	Coefficient	Robust Std, Err	Coefficient	Robust Std, Err
Education	-0.06	0.05	0.03 ^c	0.02	0.06 ^a	0.40
Log crop income share			0.02	0.05	-0.13	0.30
Log Livestock income share			0.09 ^b	0.05	-0.09	0.18
Log Irrigation income share			0.54 ^a	0.43	0.08	0.09
Log non-agriculture income share			0.13 ^b	0.05	0.16	0.25
TLU	0.35 ^b	0.14	0.03	0.02	0.04	0.07
Cultivable land size	0.15	0.12	0.03	0.02	-0.07	0.08
Extension agent contact	-0.06 ^b	0.03				
Distance to output market	0.005 ^b	0.003				
Distance to input market	-0.02 ^b	0.02				
Small-scale irrigation	0.99 ^a	0.89				
HH age	0.02	0.03				
HH farm experience	0.22	0.02				
Group membership	-0.035	0.34				
Weather forecast access	0.45	0.41				
Asset ownership	0.87 ^b	0.42				
Soil fertility	0.98 ^b	0.45				
Access to credit	0.08	0.35				

^{a, b, c} = a significant level of 1%, 5% and 10%, respectively

There was positive relationship between access to safe water and sanitation with food security. A related study conducted by (Young, 2021) indicated that water and sanitation significantly contributed to food security by ensuring enhanced absorption capacity of the body and nutrient use in the food. Additionally, sanitation safeguards human fecal pollution thereby spread of disease can be reduced. The study revealed a positive and significant relationship between TLU and food security. Livestock provides households with food directly (meat and milk) and as well as income generation through sales and the money can be used again for purchasing food during critical times.

The estimates of the treatment effects of the adoption of CSA on income and food security of households are presented in Table 4. The Treated average Treatment effects (ATT) category measures the change between the adopters' welfare and what they could have if they had not adopted CSA. On the other hand, the Untreated Average Treatment effect (ATU) examines the change in the welfare of non-adopters and their counterfactual effects. Unlike the mean difference reported in Table 1, these estimates account for selection bias.

The ATT shows that household income and food security for the treated are positive and statistically significant with 1.58 and 0.81, respectively. This shows that adopters would have become food insecure and lost their income had they had not adopted CSA technology. However, the ATU was -0.49 and statistically significant for the log household income of smallholder farmers, but it was found higher for food security (0.39), though it was not found to be statistically significant. Likewise, the outcomes of average treatment effects (ATE) from ESR show that, had the non-adopters CSA technologies, they would have attained crop income gains. These results show that, had adopters not adopted CSA technologies, they would have been worse off, in terms of welfare. In terms of food security, non-adopters would have benefited, had they adopted CSA technology. As shown in Table 17, both household income and food security of adopters were significantly affected by CSA adoption. This finding is in line with past studies,

Table 17: Results of the average treatment effects on food security and household income

Index	Food security			Income		
	Estimate	Std Err.	<i>t</i> value	Estimate	Std Err.	<i>t</i> value
ATT	1.586	0.091	17.701 ^c	0.814	0.024	42.81 ^c
ATU	0.390	0.299	1.267	-0.491	0.072	-6.41 ^c
ATE	1.439	0.092	17.258 ^c	00.682	0.033	29.61 ^c

^{a, b, c} = a significant level of 1%, 5% and 10%, respectively

which supplement this study with evidence of the positive contribution of adoption of CSA technology on household welfare (Abegunde et al., 2022c; Bongole et al., 2022; Musafiri et al., 2022; Sam et al., 2021). A study in the Nyando basin of Kenya by (Ogada et al., 2020) found that farmers who adopted CSA were more food secure as compared to non-adopters. The study demonstrated a robust relationship between CSA adoption and food security. Therefore, interventions of CSA aiming at food security improvement in smallholder farming communities may have significant welfare gains for smallholder farmers. In general, CSA technologies improve household welfare through enhanced agricultural productivity.

5.6 Implications for policy and practice

The agriculture and food system interface, defined by CSA where its objectives are sustainably increasing agricultural production, improving community resilience, and mitigating climate change impacts is on the fast track to integrating into the global developmental agenda (Gebre & Rahut, 2021). Nevertheless, assembling the empirical evidence has complicated the transformation

of the concept of CSA into concrete actions (Wekesa et al., 2018). Therefore, evaluating the present knowledge on CSA's effectiveness to achieve the intended benefits and at the same time informing the discourse on agriculture, food, and climate change is an urgent need (Young, 2021). Evidence-based decisions through formulating workable policies and knowledge of technology transformation are, therefore, key. Considering development priorities is the first step as CSA should contribute to employment opportunity building, market, and education opportunities. The approach is termed smart because a range of key development issues is addressed by CSA (Kebebe, 2019). The next agenda must be connecting interdisciplinary research, policy, and practice. This enhances decision-making at all levels because a broader base of field experience and scientific evidence is crucial for decision-making (Chen et al., 2021). Integrating landscape systems with farms such as integrating crops, livestock, fish, and trees on the entire landscape or farms can improve productivity, and strengthen farming system resilience and income which thereby improve household welfare (Aravindakshan et al., 2018). In formulating CSA policies and practices, the inclusion of women and youth capacity building plays an important role in achieving the goals of CSA. Leadership skills as well as farming and facilitation skills can be established through the support of local people tailoring climate information, avail materials, and communicating needs (Fite et al., 2022). In conclusion, policies, practices, and regulations must be consistent for CSA to be effective.

5.7 Conclusion

This research assessed the impact of CSA on household welfare, using the ESR model. Variables associated with fertility status of the soil, TLU, access to input markets, and asset ownership emerged as showing a significant impact on farmers' decisions on CSA adoption. The ATT is positive and significant, which justifies the adoption of CSA resulting in a significantly positive impact on farmers' welfare. From these findings, several policy implications can be drawn. The government needs to consider incentive provisions for agro-dealers in agricultural business investments that sell inputs in rural areas. Government taxes should also be reduced for agro-dealers so that inputs will be accessible nearby to farmers. The government has to also provide incentives for financial service providers, to avail financial services affordable to agro-dealers and to enable them to store the necessary inputs in sufficient quantities. Alternatively, manufacturers of inputs or buyers of agricultural products can also be beneficial to these incentives, to encourage

them to foster mutually beneficial and flexible arrangements of marketing with rural agro-dealers. The findings of this study show that reducing the distance of the input market will go a long way in maximizing the probability of adoption of CSA technology, which is related to enhanced productivity. Increased productivity will, in turn, improve household welfare by increasing household income and food security. Additionally, food availability alone does not guarantee household food security, as it needs to be implemented by access to safe water and good sanitation. Development practitioners have to target educated farmers due to their greater adoption ability. Information, Education, and Communication (IEC) need to be promoted CSA adoption to suit uneducated farmers. The findings of this study also indicated that there exists a robust association between CSA and food security (through a positive and significant ATT). As a result, climate-smart agricultural interventions in smallholder farmers may actually have positive and significant household food security and income benefits.

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CHAPTER 6: SYNERGIES AND TRADE-OFFS OF CLIMATE-SMART AGRICULTURE (CSA) PRACTICES SELECTED BY SMALLHOLDER FARMERS IN GESHY WATERSHED, SOUTHWEST ETHIOPIA

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SYNERGIES AND TRADE-OFFS OF CLIMATE-SMART AGRICULTURE (CSA) PRACTICES SELECTED BY SMALLHOLDER FARMERS IN GESHY WATERSHED, SOUTHWEST ETHIOPIA

6.1 Abstract

Mainstreaming climate-smart agriculture (CSA) practices in most development programs/projects can increase smallholder farmers' capacity and awareness to improve food security and establish sustainable livelihoods through resilient agricultural systems, while achieving adaptation and mitigation benefits. Hence, valuable insights can be obtained from smallholder farmers in responding to present and forthcoming challenges of climate change impacts. However, there is little research work on trade-off and synergy assessments. Taking Geshy watershed in Southwest Ethiopia as a case study area, both quantitative and qualitative data analysis were undertaken in this study. The data were collected from 15 key informant interviews, 6 focus group discussions, and 384 households to answer the following questions: (1) what are the top five preferred CSA practices for smallholder farmers in Geshy watershed when coping with the impacts of climate change? (2) What is the performance of the preferred CSA practices? And (3) which trade-offs and synergies are experienced upon the implementation of CSA practices? The study came up with the most preferred CSA practices such as the use of improved crop varieties, small-scale irrigation, improved animal husbandry, the use of efficient inorganic fertilizers, and crop rotation with legumes. The selected CSA practices showed that the productivity goal exhibit the best synergy, while the mitigation goal has trade-offs. The study also showed that the use of improved crop varieties causes high synergies in all three goals of CSA practices. Small-scale irrigation provides a medium synergy on productivity goal but high synergy for adaptation and mitigation goals. Improved animal husbandry showed a high synergy with the adaptation goal, a relatively lower synergy with the productivity goal, and a trade-off with the mitigation goal. The use of efficient inorganic fertilizers showed maximum synergy for the productivity and adaptation goals. Crop rotation with legumes also exhibited high synergy with the productivity and mitigation goals but a relatively lower synergy with the adaptation goal. These results can provide evidence to various stakeholder farmers in the value chain that the impacts of climate change can be addressed by the adoption of CSA practices. In general, CSA practices are considered indispensable for sustainable agriculture development in the face of climate change. Smallholder farmers prefer CSA practices that help to increase crop productivity and household resilience to climate change impacts. The results generate a vital foundation for recommendations to smallholder farming decision-makers. It also sensitizes actions for innovative and sustainable methods that are able to upscale the preferred CSA practices in the agricultural system in Geshy watershed of Southwest Ethiopia and other regions.

Keywords: Climate-smart agriculture (CSA), Synergies, Trade-offs, Productivity, Adaptation, Mitigation, Geshy watershed

6.2 Introduction

In developing countries where agriculture is the mainstay of the economy, one of the proven measures to reduce poverty is the development of the agriculture sector (Diro et al., 2022). However, the major threat to agriculture remains the climate change (Ochieng et al., 2016), which is currently highly impacting on agriculture and food security (Habtewold, 2021; Rafik et al., 2022). Global temperature has increased by 0.80°C over the past century and is expected to rise by 1.50°C–4.80°C over the next 100 years. This increase in global temperature is supposed to change climatic patterns like droughts, floods, and El Nino and La Nina incidents (Arora, 2019). The consequences of climate change have led to the reduction of available natural resources (biodiversity, soil, and water), the decline in agricultural outputs, and the decrease in household income, particularly in vulnerable regions (Gitz et al., 2016; Ray et al., 2019). The effects are, moreover, affecting food prices worldwide, altering global crop quality and yields, and influencing the security and nutritional values of foods (Malhi et al., 2021).

The economy of Ethiopia is highly reliant on agriculture, which contributes 85.00% to foreign exchange, 52.00% to GDP, and 80.00% to employment (Yigezu, 2021). Agriculture sector is characterized by small-scale and crop-livestock mixed production systems with very low productivity. The contributing factors for reduced productivity include the dependence on traditional farming system, climate change including extremes, deforestation, poor marketing, and poor infrastructures (Gitz et al., 2019). Over the past decade, the average maximum and minimum temperatures in Ethiopia have been increased by about 0.10°C and 0.25°C, respectively (NMA, 2022). In contrast, in a flood-prone Bangladesh in South Asia, agriculture accounts for 17.22% of the national GDP, and almost 150 million people are farmers, occupying more than 55.00% of the total population (Hossain et al., 2021). Agriculture in Bangladesh is highly impacted by catastrophic cyclones, leading to the demolishing of significant large amounts of farmlands and the deaths of people. The fluctuation of rainfall, the sharp rise of temperature, and the degradation of arid environments in coal mine areas are the major contributing factors recorded impacts on agriculture. In response, flood insurance (as a climate change adaptation strategy) and the re-vegetation of coal mine-degraded areas with native woody species under optimum water and nutrient resources were proposed as a panacea to solve the problem of climate change (Hossain et al., 2021; Rana et al., 2023). Vulnerability is associated with poverty (the loss of adaptive or coping

capacity). Adaptive capacity is understood as the potential of a system to take the advantage of opportunities by successfully responding to climate change and its impacts (Mihiretu et al., 2021).

Smallholder farmers constituting the larger proportion (85.00%) of the whole population in Ethiopia are exceptionally victims of climate change (including extremes) due mainly to their weak adaptive capacity (Hundera et al., 2019). One of the approaches proposed by various studies for enhancing the adaptation and mitigation of climate change is the implementation of the climate-smart agriculture (CSA) (Gezie, 2019; Hundera et al., 2019; Ghimire et al., 2022). The 3 interim objectives of CSA are as follows: (1) increasing agricultural sustainable productivity, (2) forming resilient society by creating healthy farming and food systems, and (3) reducing greenhouse gas emissions from agriculture (Datta et al., 2022). Hence, agricultural practices meeting these objectives are regarded as “climate-smart” (FAO, 2021).

Intensifying the farm-level use and improving the uptake of CSA practices among farming communities are imperative to ensure production system resilience to create sustainable food security and livelihoods while tackling the issues of climate change (Mereu et al., 2018). Trade-offs and synergies are the typical characteristics of interventions for CSA (Girardello et al., 2019). Various farm-level management activities and practices deliver two or more of either synergies or trade-offs (Ogola and Ouko, 2021). Synergy, based on Baniassadi and Sailor (2018), is the relationship between two or more actions that result in an effect less or higher than the sum of the effects of individuals. Thus, positive results are termed synergies and negative outcomes are called trade-offs. For smallholder farmers in Geshy watershed, CSA practices are considered to be parallel outputs rather than alternative targets (Kearney et al., 2019; Liu et al., 2022). Despite the inevitable trade-offs among the 3 goals of CSA practices (productivity, adaptation, and mitigation), ensuring sustainable productivity for smallholder farmers in Geshy watershed without affecting the adaptation and mitigation benefits remains a challenging task for researchers and policymakers.

An all-inclusive approach is essential to maximize benefits and minimize the negative outcomes of CSA practices. While implementing CSA practices, trade-offs differ and may affect both the environment and smallholder farmers’ outputs. Smallholder farmers in Geshy watershed aspire to get as much harvest from their agriculture, which can be influenced by the type of input or practices used in their farms. A combination of various CSA practices can enhance the productivity of farms, thus improving household income (Howe et al., 2014). The adoption of some CSA practices,

however, can increase the use of labor and lead to pollution and emission, which brings trade-offs (Girardello et al., 2019). Hence, carefully designing CSA practices is required to address synergies and trade-offs among productivity, adaptation, and mitigation goals.

In looking for locally appropriate alternatives to improve the resilience of the farming system and households to climate change, the analysis of trade-offs has come out as a fundamental process to the suitability of agricultural innovations (Lopez-Ridaura et al., 2018). For smallholder farmers in Geshy watershed, there are a number of possible adaptation practices for the management of climate risk from moderate to extreme. General practices of field management, changes in crop management, farm risk mitigation practices, soil and water conservation, and access to information are vital to improving the adaptation capacity of agriculture to climate change impacts (Mossie, 2022). These alternatives can also maximize crop yield, improve the efficiencies of production and net household income, and where possible, reduce the emissions of greenhouse gases. In many ways, the above 5 practices have effectively improved production, increased income, and produced resilient agricultural communities (Dagnachew et al., 2020).

Although the purpose of CSA practices is to simultaneously achieve all 3 goals (productivity, adaptation, and mitigation), it should be recognized that a triple win may not be achieved in all recommended and applied practices. In Ethiopia, knowledge gaps exist on how smallholder farmers maximize synergies and reduce trade-offs for different CSA intervention implementations. Therefore, multi-stakeholder analysis is crucial to improve the possible practices of CSA. This study is, therefore, aspiring to address this gap in knowledge by conducting a trade-off and synergy analysis of CSA practice adopted by smallholder farmers in Geshy watershed from the perspectives of smallholder farmers and experts. The assessment will contribute to the scarce literature on the opinions from smallholder farmers and experts about the adaptation and mitigation of climate change in Ethiopia.

6.3 Materials and methods

6.3.1 Identification of climate-smart agriculture (CSA) practices

Based on the survey results collected from 384 households, we identified the available CSA practices in Geshy watershed. The confirmation of the available CSA practices was determined using the Ethiopian CSA roadmap and the case study report of the FAO (2021b). A total of eighteen CSA practices were identified and then grouped into heterogeneous principal clusters

using Principal Component Analysis (PCA). We rotated the components by employing the orthogonal rotation method and obtained five principal components (CSA practices), as presented in Table 18. The orthogonal rotation method of PCA resulted in a smaller number of highly correlated practices under one component for the ease of generalization and interpretation of the group (Zhou et al., 2021).

Table 18: Discovering climate-smart agriculture (CSA) practices through household survey

CSA strategy	CSA practices discovered through household survey
Crop management activities	Use of efficient inorganic fertilizer Changing planting date Crop rotation using legumes Use of organic fertilizer
Field management and climate change mitigation practices	Use of cover crops Alley cropping Tree planting for windbreak and shelter for crops Use of mulching Use of bio-briquettes
Farm risk reduction practices	Feed improvement Use of improved crop varieties Small-scale irrigation Improved animal husbandry
Supplementary income generation practices	Apiculture Poultry farming Grass strip use
Soil and water conservation practices	Terraces use

6.3.2 Analytical framework

6.3.2.1 Ranking of CSA practices

All the 18 CSA practices listed are the top 5 high-scoring clusters of practices used by smallholder farmers at present, based on PCA. The performance of the total garnered score of each practice among the whole was compared in the process of scoring. We ranked practices based on the average total score of each practice divided by the number of smallholder farmers. The first number indicated the practice with the highest score and the last number denoted the practice with the least

score. Smallholder farmers were requested to choose the top 5 CSA practices out of the 18 practices based on their priorities and perceptions with respect to the 3 goals of CSA practices. Each practice was rated 5 points for each top 5 ranking. The practice ranked first can earn 5 points, while the practice ranked last (5th) can only earn 1 point. The total score of each practice was then computed by multiplying the point of each rank by the frequency of responses in the selection. Eventually, the practice with the maximum average score was rated the first and the least score was given to the practice that was ranked the last, according to the study of Ogola and Ouko (2021).

6.3.2.2 Analysis of synergies and trade-offs

Within the three goals of CSA practices, smallholder farmers were requested to score the practices they prioritized to examine the performance of each practice on the value chain in Geshy watershed. We selected the top five CSA practices based on the level of performance using a 3-point Likert scale: low=1, medium=2, and high=3. Normalizing the average scores into values ranging between 0.00 and 1.00 was the next step, where 1.00 signified a greater contribution to the goal and 0.00 meant a lower contribution. The average values were then normalized and the weight range was set as 0.00–0.33 for low performance, 0.34–0.66 for medium performance, and 0.67–1.00 for high performance. The results plotted in the spider graph were used to analyze and visualize how each practice preferred establishing the trade-offs and synergies to the 3 goals of CSA practices.

6.4 Results and Discussion

6.4.1 Smallholder farmers' preferences on the top 5 CSA practices

The top five CSA practices preferred by smallholder farmers are presented in Figure 9. These practices included the use of improved crop varieties (ranked 1st), small-scale irrigation (ranked 2nd), improved animal husbandry (ranked 3rd), the use of efficient inorganic fertilizers (ranked 4th), and crop rotation with legumes (ranked 5th). The preference of the top CSA practices by smallholder farmers was based on the level of economic returns generated, household resilience created, information availability, the ease of implementation, the improvement of productivity, and the adaptability to climate change.

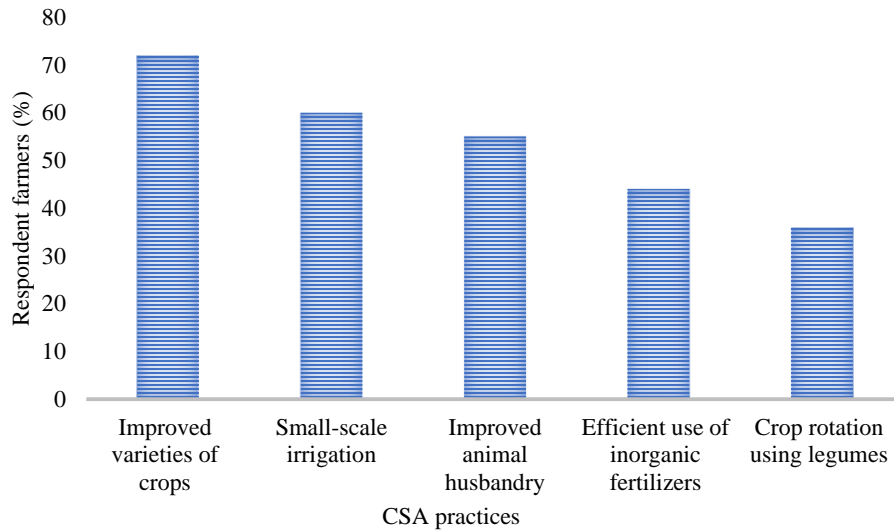


Figure 10: Percentage of smallholder farmers responses to the top 5 CSA practices

6.4.2 Performance of the top 5 CSA practices on the 3 goals (Productivity, Adaptation, and Mitigation)

6.4.2.1 Productivity

The use of improved crop varieties, the use of efficient inorganic fertilizers, and crop rotation with legumes had high weights for the goal of productivity, underlining high contributions to agricultural production (Fig. 10). On the other hand, small-scale irrigation and improved animal husbandry exhibited medium weights for productivity goal.

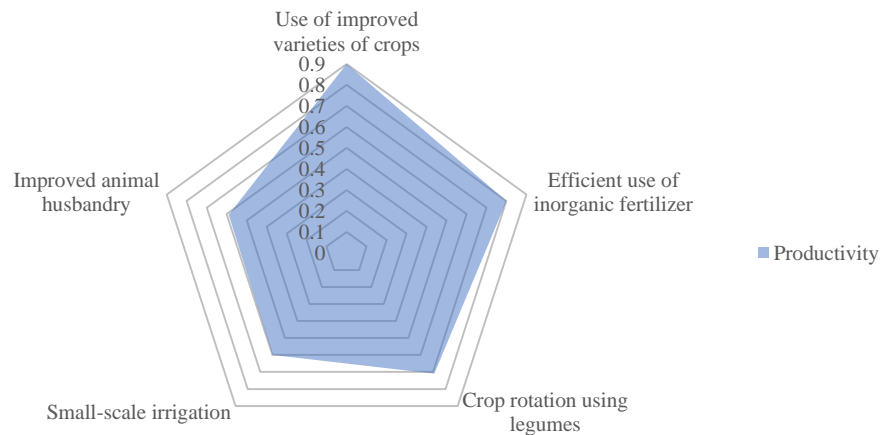


Figure 11: Performance of the top 5 CSA practices on productivity

6.4.2.2 Adaptation

Improved animal husbandry, small-scale irrigation, the use of improved crop varieties, and the use of efficient inorganic fertilizers had high weights for the goal of adaptation; hence, they have been remarkably resilient to the impacts of climate change on the agricultural system in Geshy watershed (Fig. 11). On the other hand, crop rotation with legumes had a medium weight making it effective for adaptation goal.

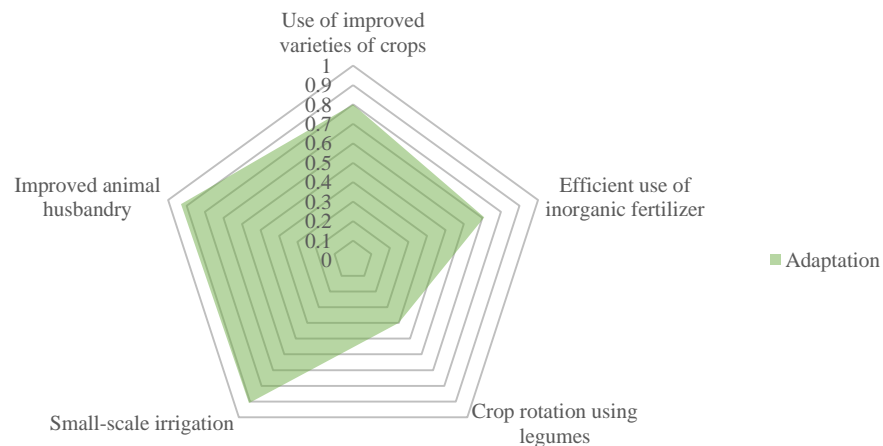


Figure 12: Performance of the top 5 CSA practices on adaptation

6.4.2.3 Mitigation

The findings further showed that the use of improved crop varieties, small-scale irrigation, and crop rotation with legumes exhibited high mitigation effects on climate change in the agricultural system in Geshy watershed. In contrast, the use of efficient inorganic fertilizers offered medium mitigation to climate change effects (Fig. 12). Nevertheless, improved animal husbandry resulted in a lower weight of 0.17. Likewise, a study conducted by Singh (2017) confirmed that small-scale irrigation and crop rotation with legumes have been shown to mitigate the effects of climate change by improving residual carbon biomass in the soil.

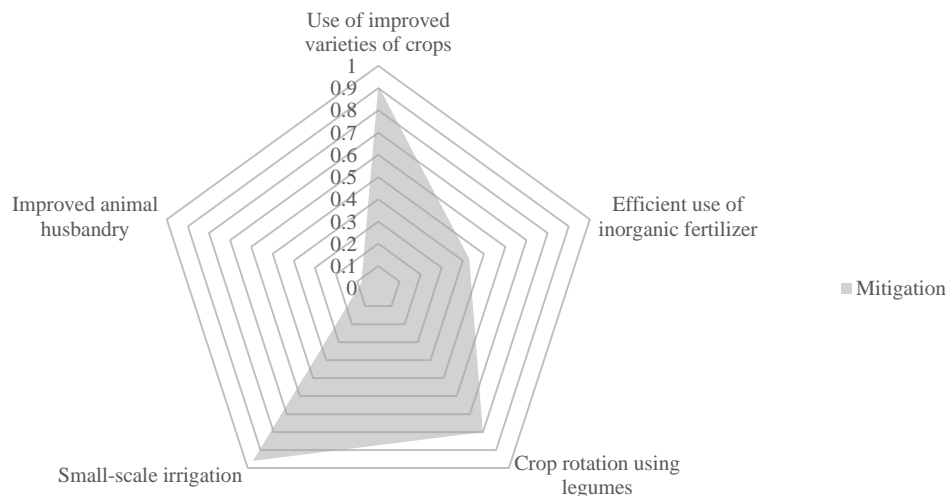


Figure 13: Performance of the top 5 CSA practices on mitigation

6.4.3 Analysis of synergies and trade-offs among the selected CSA practices

The performance of goals with values less than or equal to 0.33, which correspond to low weights, was regarded to induce trade-offs, while synergies corresponded to medium to high weights with values greater than or equal to 0.34. Nevertheless, high synergies resulted in practices with weights exceeding or equal to 0.67. Generally, except for improved animal husbandry that showed trade-offs in the mitigation, all the other practices were assessed to create synergies among the 3 goals (productivity, adaptation, and mitigation) (Table 19). The result indicated that the best-performing goal was productivity with the implementation of the selected CSA practices. Thus, the goal of productivity was greatly synergetic, followed by the goals of adaptation and mitigation (Table 19).

Table 19: Trade-offs and Synergies of CSA

CSA practices	Productivity	Adaptation	Mitigation
Improved crop varieties	++	++	++
Small-scale irrigation	++	++	++
Improved animal husbandry	++	++	-
Efficient use of inorganic fertilizer	++	++	+
Crop rotation using legumes	++	+	++

Synergies high (++), synergies medium (+), Trade-off (-)

The study has shown that the use of improved crop varieties caused high synergies in all 3 goals of CSA practices. This might be associated with the fact that smallholder farmers are assured of maximum yields, adaptive to severe climatic conditions, and minimum scale of external inputs such as fungicides and pesticides by using the improved crop varieties, as most improved seeds are disease and pest resistant compared to local seeds. The results are consistent with previous studies (Rice et al., 1998; Jha et al., 2020; Ahmed, 2022), which discovered that improved seeds are more adaptable and have better yield performance as compared to local seeds. Likewise, Takahashi et al. (2020) and Baiyegunhi et al. (2022) indicated that low maize productivity in developing countries can be attributed to the use of low-quality seeds by smallholder farmers and thereby the potential yield could be reduced. Rahman and Connor (2022) found that the adoption and promotion of improved seeds is the appropriate approach to enhance crop yields in developing countries and thus improve the food security status. In contrast, studies by Mba et al. (2012) and Ficiciyan et al. (2018) argued that the use of improved crop varieties increases inorganic fertilizers, herbicides, and agrochemicals without addition of organic fertilizers to improve the fertility of the soil, and minimize disease and pest prevalence that will cause trade-offs instead of synergy in mitigation goal. A study by Beeby et al. (2020) showed that the productivity of crops using efficient inorganic fertilizer has relatively less synergy in mitigation due to agrochemical emission. Diacono and Montemurro (2010) and Beeby et al. (2020) further augmented the role of organic fertilizers in improving the fertility of the soil for sustainable crop production.

Most Ethiopian agricultural soils (55.00%) are prone to soil erosion and acidification and are regarded as poor soils (Sinore et al., 2018; Sisay, 2019). This resulted in the constant synthetic fertilizers used to rapidly improve the fertility of the soil for crop production. Deterioration of soil quality and release of toxic substances into the atmosphere could be caused by excess and continuous use of agrochemicals such as artificial fertilizers (Khan et al., 2017; Weissengruber et al., 2018; Salem et al., 2020). Moreover, the use of fertilizers alone is not enough to increase the yield of crops; nevertheless, it must often be added with organic fertilizers to reverse soil degradation and maintain sustainable production (Bayu, 2020; Selim, 2020; Hörner and Wollni, 2021). Many experiential studies also indicated that smallholder farmers do not strictly follow the prescriptions of agrochemicals due to high disease and pest infestations (Aktar et al., 2009; Donatelli et al., 2017; Dara, 2019). This study evaluated the use of efficient inorganic fertilizers as challenging among smallholder farmers in Ethiopia. Agricultural extension workers usually

claimed that smallholder farmers do not followed the recommended amounts of agrochemicals and use a more concentrated agrochemical spray because they believe that it can quickly eradicate and kill diseases and pests than the recommended dosage. It can then be traced that the increased use of these agrochemicals could result in increased emissions from the transport and manufacture of agrochemicals, thus creating trade-offs.

The study also indicated that small-scale irrigation is a crucial CSA practice in crop production under the current climate change. Medium synergy can be provided by small-scale irrigation on productivity but high synergy for adaptation and mitigation goals. Smallholder farmers benefit from irrigation, which stabilizes crop production by supplementing rainfall and moistening the soil during dry periods. In addition, smallholder farmers are also able to produce crops and generate more income during off-seasons. Mango et al. (2018) confirmed that irrigation is an alternative best CSA practice that increases household income in addition to maximizing productivity, thereby enhancing smallholder farmers' adaptive capacity against climate change impacts. Furthermore, a study conducted by Ngango and Hong (2021) affirmed that irrigation can help mitigation efforts by keeping the nutrients ionized in the soil that could have been liberated to the atmosphere. Hence, irrigation contributes highly to the mitigation goal. However, Passarelli et al. (2018) suggested that smallholder farmers should be encouraged by policymakers to invest in suitable and appropriate approaches, such as the use of drip irrigation and solar-driven systems, to enhance the utilization efficiency of water and energy. Water storing structures like water pans can serve as water sources during water shortage periods, thereby mitigating water shortages (reducing trade-offs).

Improved animal husbandry shows a high synergy with the adaptation goal, a relatively lower synergy with the productivity goal, and a trade-off with the mitigation goal. The primary goal of animal husbandry by improving its breeds by smallholder farmers is to generate additional revenue for the family and promote household resilience, thereby increasing adaptation capacity against potential climate change impacts. This is substantiated by a study conducted by Rojas-Downing et al. (2017), who showed that improved animal husbandry can enable smallholder farmers to adapt to climate change impacts by increasing the amount of Tropical Livestock Unit (TLU) output, which is a common unit used to convert livestock numbers, and thereby improving household income, especially during the off-farm seasons. The medium synergy is indirectly increasing crop productivity by supplying organic fertilizers in the form of manure to the soil, thereby improving

animal husbandry productivity. Soil fertility and sustainable productivity are possible outcomes. A study conducted by Rojas-Downing et al. (2017) confirmed these findings that organic fertilizers in the form of manure and compost can increase soil fertility and enhance crop productivity. Conversely, as improved animal husbandry shows synergies with productivity and adaptation goals, it also has trade-offs with the mitigation goal against climate change impacts. The emission of methane gas during regurgitation and nitrogen gases from the open-laid dung are inevitable trade-offs. Gill et al. (2010) supplemented the trade-off that exists between animal husbandry and mitigation efforts. Although the emissions from improved animal husbandry is less than that from traditional husbandry practices, it is still the source of greenhouse gas emissions like methane.

Finally, the use of efficient inorganic fertilizers shows maximum synergy for the productivity and adaptation goals. Thus, the mitigation goal receives a relatively lower synergy than other goals. This result is in conformity with the study conducted by Mahmud et al. (2021) who stated that the use of efficient inorganic fertilizers has a high synergy with the mitigation goal as compared to the productivity and adaptation goals.

Crop rotation with legumes exhibits high synergy with the productivity and mitigation goals but a relatively lower synergy with the adaptation goal. The smallholder farmers have mentioned some of the benefits from crop rotation with legumes such as soil fertility improvement through nitrogen fixation, productivity increase, and no add external inputs to the soil. Moreover, crop rotation with legumes could prevent nutrient loss, increase climate resilience, and minimize the vulnerability of the agricultural system (Yu et al., 2022).

6.5 Conclusion and recommendation

This study examined the top 5 practices of CSA selected by smallholder farmers currently used in Geshy watershed of Southwest Ethiopia. It also assessed the synergies and trade-offs upon the implementation of CSA practices by smallholder farmers. The top 5 practices of CSA selected by smallholder farmers were the use of improved crop varieties, small-scale irrigation, improved animal husbandry, the use of efficient inorganic fertilizers, and crop rotation with legumes. The result, however, showed that all CSA practices contributed synergies across the 3 goals (productivity, adaptation, and mitigation) except the trade-off experienced with improved animal husbandry practice with the mitigation goal. Smallholder farmers preferred CSA practices that prioritized productivity over mitigation or adaptation goals. The implementation of CSA practices

can improve agricultural productivity, and adapt to and mitigate climate change. Moreover, this study further explored synergies and trade-offs in the performance of each goal of CSA practices adopted by smallholder farmers. Examining the synergies and trade-offs among CSA practices was fundamentally important in realizing sustainable agricultural productivity, improving the adaptation capacity, and enhancing the mitigation potential due to climate change in the farming system of Geshy watershed. The study revealed that the implementation of some CSA practices could result in trade-offs in one goal and synergies on other goals by influencing other resources or practices. Thus, a consistent and clear policy framework is needed to effectively expand and adopt CSA practices. The framework should consist of extension services, clear guidelines, technical infrastructure, policy harmonization, and incentives to avoid possible trade-offs among the 3 goals of CSA practices.

Some of the limitations of this study are the unbalanced views and knowledge of smallholder farmers on the 3 goals of CSA practices, data collection is limited to smallholder farmers and experts where policy-maker views should also be included, and the few use of analytical methods such as PCA and scoring analysis. Despite these limitations, the study contributes to major innovations, such as filling the climate change knowledge gap by experts' views, creating sustainable climate resilient impact pathways for smallholder farmers by adopting the top 5 CSA practices, and providing a good entry point for policy-makers on which technology to promote for achieving sustainable food security and livelihood improvement in the face of climate change.

Based on the findings of this study, the following recommendations can be drawn. Further research is needed to obtain and develop improved crop varieties with disease and pest outbreaks and provide reasonable prices to smallholder farmers, which can promote the application of CSA practices. To improve the quality of the soil and ensure the sustainability of Geshy watershed, it is necessary to develop the policy interventions to encourage the combined use of organic and inorganic fertilizers. Regional and national policies that promote small-scale irrigation practices should be formulated to reduce the agricultural losses due to climate change. In order to minimize smallholder farmers' vulnerability to climate-related risks, it is necessary to arrange smallholder farmers to obtain climate information through appropriate innovative diffusion pathways. This will minimize the uncertainty of climate change on CSA practices adopted by smallholder farmers in Geshy watershed and help smallholder farmers plan their agricultural activities precisely.

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CHAPTER 7: SYNTHESIS AND FUTURE RESEARCH

SYNTHESIS AND FUTURE RESEARCH

7.1 Introduction

In this research, the preceding chapters covered four major areas to understand how CSA can integrate adaptation and mitigation strategies for smallholder farmers in the mixed farming system of Geshy watershed. This included justifying effects of climate change, CSA technologies that can be used to mitigate and adapt the potential negative effects, adoption (determinants, patterns, and impact) and suggesting optimal CSA combinations for improving food security and household welfare. This final chapter summarizes empirical findings in objectives. Additionally, the chapter discusses areas of further investigations and the contribution of the research.

7.2 Synthesis (Key Findings and Summary)

The concept of climate-smart agriculture (CSA) has recently been highly promoted, in Sub Saharan Africa (SSA) including Ethiopia, to address the adverse impacts of climate change and variability. The government of Ethiopia in collaboration with other development and research organizations has promoted CSA given 85% of the whole population rely on agriculture for their livelihoods. In addition to the reliance on rain-fed agriculture coupled with climate change effects, small holder farmers are also facing other limitations such as inappropriate technology and resource constraints. This study has examined the impact of CSA adoption on food security and household welfare in the Geshy watershed of Southwest Ethiopia. The study reviewed several approaches, methods and knowledge on climate change and how it affects agricultural productivity and household income.

The review findings indicated that SSA including Ethiopia is vulnerable and farmers can opt for a basket of CSA technologies to address the impacts of climate change. In addition to integrated watershed management, conservation agriculture has been the dominant CSA technology in Ethiopia. Available empirical studies were limited to discussing patterns of adoption and optimal mix modelling of CSA technology combinations for adoption by farmers. Empirical research on CSA, while providing evidence on impact and adoption, largely focus on the adoption of single technology. Farmers adopt multiple technologies in reality to suit different constraints. There are very few research findings that model optimum mix for farmers adopting various CSA technology bundles.

A brief summary of the key findings of this research is presented hereunder by outlining the six research questions indicated in this study.

The first research question was focusing on identifying the spatiotemporal variabilities and trends in temperature and rainfall and its implications in climate-smart agriculture in the study area. In response, the study assessed the spatiotemporal variability and trends of rainfall and temperature of the years 1986-2020. As a global wide-ranging phenomenon, smallholder farmers in the Geshy watershed also faced the impacts of temperature rise and precipitation fluctuations, leaving them vulnerable. The typical characteristics of trends and variabilities and impacts of temperature and rainfall included a rise in the average annual temperature with 0.08°C and a rainfall variability with an average annual coefficient of variation (CV) ranging from 24.5% to 27.3% in the five meteorological stations. The late onset and early cessation of rainfall, which is becoming unpredictable, also results in changes in the length of the growing period, a decrease in crop productivity, disease, and pest attacks, and reduced household income. Along with other socioeconomic (such as family size, lack of knowledge, educational status, etc.) and biophysical factors (such as land size, soil fertility status, topography, etc.), the likelihood of these changes and variabilities, in aggravating the food insecurity situation and household resilience, can be considered paramount (Fig. 14).

On the other hand, the adoption patterns of CSA practices among household typologies was examined to address research question number two of this study. Thus, using a multivariate analysis technique that combined Principal Component Analysis (PCA) and cluster analysis, this study generated technology bundles and household typologies. The findings then revealed that CSA patterns varied across household typologies with experienced and resource-endowed farmers adopting more CSA technologies such as small-scale agriculture and crop rotation that require more resources while resource-constrained clusters avoided resource-intensive ones. Farmers are heterogeneous and will choose and adopt various CSA technologies to address limitations and meet various livelihood objectives. Some of the CSA compete for farm resources while some others are complementary. This leads to diversified technology bundles that were noticed in the study. In tailoring awareness and promotional strategies, understanding such patterns is important for various target farmers who favor certain CSA bundles. An instance would be promoting complimentary technologies in combination rather than individually (Fig. 14).

Research question number three was again addressed by examining the determinant factors for CSA adoption. In reply, using Cragg double hurdle model, factors including livestock income share, weather information, distance to market, credit access, and asset ownership were found to play key role in making decisions for adoption. The intensity of adoption is then further influenced by factors such as labor size, age and sex age of household head, extension contact frequency, credit access, and access to weather forecast, distance to output and input market, off-farm income. The other fundamental issue in analyzing CSA adoption patterns was establishing the determinants of multiple CSA technologies in Geshy watershed. The result of the analysis showed that household head gender, farm characteristics (labor size and soil type), and institutional factors (credit access, market access and information access) are the major factors determining the adoption of a combination of various CSA technologies (Fig. 14).

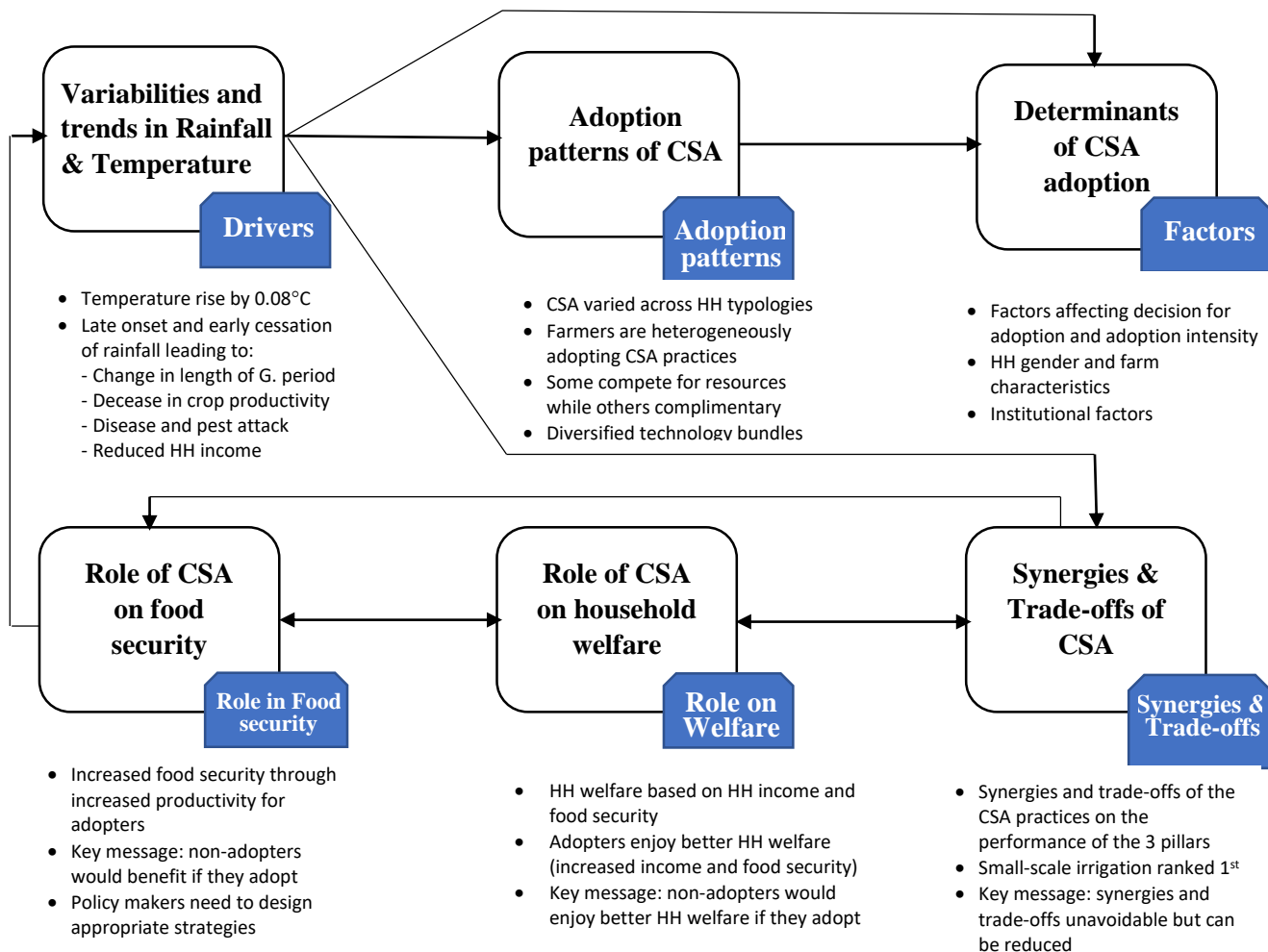


Figure 14: Synthesis (schematic representation of key findings and summary)

The impact of CSA adoption on improving agricultural productivity was investigated to answer research question number four. The result evidenced increased food security status for households adopting CSA. The key message of this section was that adopters are benefiting and non-adopter households would benefit if they adopted. CSA could contribute to food security through increased productivity. The section concluded that policymakers should design appropriate strategies and policies aiming at improving the knowledge of farmers on CSA technologies. This might include credit access, early warning systems, and programs that increase information access and market access to facilitate CSA scaling up in smallholder farming communities (Fig. 14)..

To address research question number five, the impact of CSA on household welfare indicators i.e. food security and household income were analyzed. The analysis result showed that the adoption of CSA increased both food security and household income whereby welfare is enhanced. As discussed in the above section, the important message of this finding was that adopters are benefiting from enjoying better household welfare than non-adopters and the non-adopters could benefit if they adopted CSA technologies. CSA could contribute to enhanced household welfare through increased productivity and income (Fig. 14)..

Finally, the benefits (synergies) and constraints (trade-offs) of adopting CSA justified by the three pillars of CSA i.e. productivity, adaptation, and mitigation, based on available CSA technologies, were investigated to answer question number six.. The most preferred technologies by farmers included small-scale irrigation, improved crop varieties, the use of efficient agrochemicals, crop residue management, and diversified crop production. While the productivity pillar was the best-performing pillar from the rest for the selected CSA practices, one has to understand that trade-offs were also observed across all pillars. The inclination of farmers towards maximizing the productivity pillar of all practices and the less attention given to the mitigation pillar was because farmers need to produce more food to meet their household demands rather than the mitigation pillar of unobservable long-term climate change impacts. The key message of this finding was that in any CSA technology adoption synergies and trade-offs are unavoidable and farmers should work towards maximizing synergies and reducing trade-offs (Fig. 14).

7.3 Contribution to new knowledge

Adoption of CSA was low despite the potential of CSA technologies and efforts to promote them in the smallholder mixed farming system of the Geshy watershed. Various studies have mainly

focused on evaluating the determinants of the adoption of single CSA technology in most cases while farmers adopt a combination of technologies to suit their needs. Therefore, this dissertation investigated the popular adoption patterns i.e. CSA technology bundles by various typologies of farmers. In addition, the study analyzed the factors influencing the adoption of these popular combinations of technologies. Many studies addressed the CSA impact and few and none in Ethiopia has further gone to model optimal technology mix for these CSA combinations. This study modeled and came up with an optimal combination of CSA technologies that could deliver maximum benefits of food security and household welfare.

7.4 Possible future research areas

There are a number of quite researchable areas with regard to CSA that need attention. The study's empirical findings are based on farm-level cross-sectional data. Future research could improve generalizations based on such an approach considering panel data collection. Furthermore, future studies could analyze CSA in the horticulture value chain of smallholder farmers as well as which crops, particularly, are greatly profitable. The effects of various policies on CSA adoption also need to be studied. Further, given the various availability of resources and input and output ranges of price for various households over time, it could be relevant to consider making some simulation analysis (variable resource programming and variable price) to suggest broader possibilities of farm plans.

Appendix 1: Consent form

At the beginning of each interview, we should obtain an Informed Consent from all participants. This should include a brief description of the research work and activities and that information will be kept confidential (we will not associate anyone's name with specific comments – unless they ask us to). Participation is voluntary – if they do not wish to participate, they do not have to.

The following statement (adapted from CCAFS 2015) should be read and explained to the participants. The informants should then sign and date the form. These forms should be kept with the interview notes.

Good morning/afternoon. We are coming from.....

With permission from the local government. We are conducting a study to understand the farming systems and challenges and opportunities in the region and have chosen to work in this district/sub-country.

We would like to ask you some questions that should take about one hour of your time. We would like to share some of this information widely in order for more people to understand how food is grown and used in this region and the issues that are faced regarding food production and soil, water, and land management.

The information you provide will be confidential; your name will not be associated with the specific information you give us; we will report trends that are identified from the data analysis. The information is used purely for research purposes; your answers will not affect any benefits or subsidies you may receive now or in the future. Do you consent to be part of this study? If there are questions that you would prefer not to answer, then we respect your right not to answer them.

Please sign and date here indicating that you agree to participate:

Name

Signature

Date

Appendix 2: Household Survey questionnaire

PART I) GENERAL INFORMATION	Tick, fill or circle
1.1 Enumerator's name	[]
1.2 HH ID	[]
1.3 Kebele	[]
1.4 Village	[]
1.5 Date	[/ /]
PART II) DEMOGRAPHIC CHARACTERISTICS	
2.1 Respondent's name	[]
2.2 Name of HH head	[]
2.3 Is the respondent HH head?	[]
2.4 If no, what is the relationship with HH?	[]
2.5 Sex of HH head	2.4a Male [] 2.4b Female []
2.6 Number of HH members	[]
2.7 Total earning hands	[]
2.8 HH age categories (in years)	2.8a [< 1, M _____, F _____] 2.8b [1-9, M _____, F _____] 2.8c [10-17, M _____, F _____] 2.8d [adults, M _____, F _____]
2.9 Age of HH head (years)	[]
2.10 Education status of HH members	2.10a Illiterate [] 2.10b 1-5 grade [] 2.10c 6-8 grade [] 2.10d 9-10 grade [] 2.10e 11-12 grade [] 2.10f University, specify _
PART III) SOCIOECONOMIC FACTORS	
3.1 Land size (ha)	[]
3.2 Principal economic activity of the HH	3.2a) Farming [] 3.2b) Trading [] 3.2c) Formal employment [] 3.2d) Other, specify.....
3.3 If the answer to 2.2 is farming, what farm activities involved	3.3a Crop farming [] 3.3b Livestock farming [] 3.3c Fish farming [] 3.3d Mixed farming [] 3.3e Other specify.....
3.4 Monthly HH income in Birr	3.4a < 1,000 [] 3.4c 5,000-10,000 [] 3.4b 1,000-5,000 [] 3.4d > 10,000 []
PART IV) HOUSEHOLD PERCEPTION ON CSA	
4.1 Are you familiarized with the concept of CSA?	4.1a Yes [] 4.1b No []
4.2 Do you have access to weather forecasts?	4.2a Yes [] 4.2b No []
4.3 Number of contacts with extension in the last 12 months	[]
4.4 Which one/combination of practices do you practice in your farm?	4.4a Practicing alley cropping [] 4.4b Small-scale irrigation []

	4.4c Use of organic fertilizer	<input type="checkbox"/>	
	4.4d Use of improved crop varieties	<input type="checkbox"/>	
	4.4e Use of efficient inorganic fertilizer	<input type="checkbox"/>	
	4.4f Planting trees for windbreak and shelterbelts	<input type="checkbox"/>	
	4.4g Use of mulching	<input type="checkbox"/>	
	4.4h Changing planting dates	<input type="checkbox"/>	
	4.4i Use of cover crops	<input type="checkbox"/>	
	4.4j crop rotation using legumes	<input type="checkbox"/>	
	4.4k Improved animal husbandry	<input type="checkbox"/>	
	4.4l Poultry farming	<input type="checkbox"/>	
	4.4m Use of terraces	<input type="checkbox"/>	
	4.4n Apiculture	<input type="checkbox"/>	
	4.4o Feed improvement	<input type="checkbox"/>	
	4.4p Sheep fattening	<input type="checkbox"/>	
	4.4q Use of grass strip	<input type="checkbox"/>	
	4.4r Use of bio-briquettes	<input type="checkbox"/>	
4.5 Do you know the benefits of adopting CSA?	4.5a Yes	<input type="checkbox"/>	4.5b No <input type="checkbox"/>
4.6 If yes what benefit/combination of benefit?	4.6a Increases productivity	<input type="checkbox"/>	
	4.6b Enhances resilience	<input type="checkbox"/>	
	4.6c Efficient natural resources use	<input type="checkbox"/>	
	4.6d Enhances food security	<input type="checkbox"/>	
	4.6e More profitable and less costly	<input type="checkbox"/>	
	4.6f Any other, specify.....		
4.7 Do you know any constraint/trade-off in CSA?	4.7a Yes	<input type="checkbox"/>	4.7b No <input type="checkbox"/>
4.8 If yes, what constraints (trade-offs)?	4.8a Land shortage	<input type="checkbox"/>	
	4.8b Productivity shadows other pillars	<input type="checkbox"/>	
	4.8c Uncertain returns	<input type="checkbox"/>	
	4.8d High input costs	<input type="checkbox"/>	
	4.8e Demand more labor	<input type="checkbox"/>	
	4.8f Any other, specify.....		
4.9 Did you use any of these practices in the past and now don't? list and why?	[]
4.10 Would you like to introduce a new practice? Which one? Why? (select; classify from benefit list)	[]
4.11 Knowledge on adaptation role of CSA?	4.9a Yes	<input type="checkbox"/>	4.9b No <input type="checkbox"/>
4.12 If yes, what adaptation mechanism does it have?	4.12a Use of new adaptive species	<input type="checkbox"/>	
	4.12b Changing cropping patterns	<input type="checkbox"/>	
	4.12c Irrigation	<input type="checkbox"/>	
	4.12d Tree planting for shelter	<input type="checkbox"/>	
	4.12e Crop diversification	<input type="checkbox"/>	
	4.12f Mixed farming system	<input type="checkbox"/>	
	4.12g Adjusting sowing seasons	<input type="checkbox"/>	
	4.12h adopting higher yielding variety	<input type="checkbox"/>	
	4.12i Other, specify.....		
4.13 Knowledge on Productivity enhancement role of CSA?	4.13a Yes	<input type="checkbox"/>	4.13b No <input type="checkbox"/>
4.14 Knowledge on Mitigation role of CSA?	4.14a Yes	<input type="checkbox"/>	4.14b No <input type="checkbox"/>
4.15 If yes, how?	[]
4.16 Are you now in favor of climate smart practices?	4.16a Yes	<input type="checkbox"/>	4.16c Not decided <input type="checkbox"/>

	4.16b No <input type="checkbox"/>
4.17 If yes, explain why?	<input type="checkbox"/>
4.18 If no, explain why?	<input type="checkbox"/>
PART V) PERCEPTIONS ON CLIMATE CHANGE	
5.1 How do you understand climate change?	<input type="checkbox"/>
5.2 In your view is climate change taking place?	5.2a Strongly agree <input type="checkbox"/> 5.2b Strongly disagree <input type="checkbox"/> 5.2c Agree somewhat <input type="checkbox"/> 5.2d Disagree somewhat <input type="checkbox"/> 5.2e Neutral <input type="checkbox"/> 5.2f I don't know <input type="checkbox"/>
5.3 If you agree, please indicate from the list below what you have observed for the last 20 years that makes you conclude climate change is occurring?	5.3a Increase in temperature <input type="checkbox"/> 5.3b Increase in rainfall <input type="checkbox"/> 5.3c Decrease in rainfall <input type="checkbox"/> 5.3d Change in rainfall patterns <input type="checkbox"/> 5.3e Increased frequency and intensity in floods <input type="checkbox"/> 5.3f Increased frequency and intensity in droughts <input type="checkbox"/> 5.3g Other, specify.....
5.4 Are you concerned about these changes in climate?	5.4a Yes <input type="checkbox"/> 5.4 b No <input type="checkbox"/>
5.5 If yes, why?	5.5a Unable to plan farming activities <input type="checkbox"/> 5.5b Crop yields have declined <input type="checkbox"/> 5.5c Crops destroyed and livestock died <input type="checkbox"/> 5.5c Insufficient pasture for my animals <input type="checkbox"/> 5.5d Any other reason, specify.....
5.6 Would you agree that the changes you mentioned, have negatively affected your farming activities?	5.6a Strongly agree <input type="checkbox"/> 5.6b Strongly disagree <input type="checkbox"/> 5.6c Agree somewhat <input type="checkbox"/> 5.6d Disagree somewhat <input type="checkbox"/> 5.6e Neutral <input type="checkbox"/> 5.6f I don't know <input type="checkbox"/>
PART VI) VULNERABILITY ASSESSMENT	
6.1 Based on experience and observation how do you feel about the level of susceptibility of your crop farming to experience climatic problems you indicated?	6.1a Not vulnerable at all <input type="checkbox"/> 6.1b Moderately vulnerable <input type="checkbox"/> 6.1c Highly vulnerable <input type="checkbox"/>
6.2 Based on experience and observation how do you feel about the level of harm/damage that your crops could face/currently exposed to due to the climatic problems you indicated?	6.2a Not vulnerable at all <input type="checkbox"/> 6.2b Moderately vulnerable <input type="checkbox"/> 6.2c Highly vulnerable <input type="checkbox"/>
6.3 How has your HH become vulnerable to income shortages, food insecurity, and wellbeing	6.3a Not vulnerable at all <input type="checkbox"/> 6.3b Moderately vulnerable <input type="checkbox"/> 6.3c Highly vulnerable <input type="checkbox"/>
PART VII) ADAPTATION STRATEGIES ASSESSMENT	
7.1 Do you take measures for weather/climate change adaptation?	7.1a Yes <input type="checkbox"/> 7.1b No <input type="checkbox"/>
7.2 Which of the following methods have you used/still using to respond to climate change/variability?	

	7.2.1 Irrigation and water strategies	7.2.1a Crop watering in drought/dry spells <input type="checkbox"/>	7.2.1b Irrigation during the dry season <input type="checkbox"/>	7.2.1c Rain water harvesting <input type="checkbox"/>	7.2.1d Other..... <input type="checkbox"/>
	7.2.2 Crop choice and changing planting date	7.2.2a Using early maturing /drought resistant varieties <input type="checkbox"/>	7.2.2b Changing planting date <input type="checkbox"/>	7.2.2c Changing crops <input type="checkbox"/>	7.2.2d Stopping crop production <input type="checkbox"/>
	7.2.3 Soil conservation strategies	7.2.3a Crop covering <input type="checkbox"/>	7.2.3b Crop rotation <input type="checkbox"/>	7.2.3c Application of manure <input type="checkbox"/>	7.2.3d Erosion control measures <input type="checkbox"/>
		7.2.3e Others specify..... <input type="checkbox"/>			
7.3	How do you rate the effectiveness of the different adaptation strategies in helping to reduce farming problems associated with climate change/variability?				
	7.3.1a Crop watering in drought/dry spells	1. <input type="checkbox"/>	2. <input type="checkbox"/>	3. <input type="checkbox"/>	4. <input type="checkbox"/>
	7.3.1b Irrigation during the dry season	1. <input type="checkbox"/>	2. <input type="checkbox"/>	3. <input type="checkbox"/>	4. <input type="checkbox"/>
	7.3.1c Rain water harvesting	1. <input type="checkbox"/>	2. <input type="checkbox"/>	3. <input type="checkbox"/>	4. <input type="checkbox"/>
	7.3.2a Using early maturing /drought resistant varieties	1. <input type="checkbox"/>	2. <input type="checkbox"/>	3. <input type="checkbox"/>	4. <input type="checkbox"/>
	7.3.2b Changing planting date	1. <input type="checkbox"/>	2. <input type="checkbox"/>	3. <input type="checkbox"/>	4. <input type="checkbox"/>
	7.3.2c Changing crops	1. <input type="checkbox"/>	2. <input type="checkbox"/>	3. <input type="checkbox"/>	4. <input type="checkbox"/>
	7.3.2d Stopping crop production	1. <input type="checkbox"/>	2. <input type="checkbox"/>	3. <input type="checkbox"/>	4. <input type="checkbox"/>
	7.3.3a Crop covering	1. <input type="checkbox"/>	2. <input type="checkbox"/>	3. <input type="checkbox"/>	4. <input type="checkbox"/>
	7.3.3b Crop rotation	1. <input type="checkbox"/>	2. <input type="checkbox"/>	3. <input type="checkbox"/>	4. <input type="checkbox"/>
	2.3c Application of manure	1. <input type="checkbox"/>	2. <input type="checkbox"/>	3. <input type="checkbox"/>	4. <input type="checkbox"/>
	7.3.3d Erosion control measures	1. <input type="checkbox"/>	2. <input type="checkbox"/>	3. <input type="checkbox"/>	4. <input type="checkbox"/>
	<i>Provided that 1= Highly Ineffective, 2= Ineffective, 3= Can't tell, 4= Effective, and 5= Highly effective</i>				
7.4	What adaptation constraints do you encounter?				
	7.4.1a Small land size	<input type="checkbox"/>			
	7.4.1b Poor property rights (ownership) on land	<input type="checkbox"/>			
	7.4.1c Poor Quality of seed	<input type="checkbox"/>			
	7.4.1d Lack of drought resist varieties	<input type="checkbox"/>			
	7.4.1e High cost of DR Varieties	<input type="checkbox"/>			
	7.4.1f Inadequate training	<input type="checkbox"/>			
	7.4.1g Limited access to markets	<input type="checkbox"/>			
	7.4.1h Lack of technical skills	<input type="checkbox"/>			
	7.4.1i Irrigation water management issues at a plot	<input type="checkbox"/>			
	7.4.1j Credit facility issues	<input type="checkbox"/>			
	7.4.1k Poor extension services	<input type="checkbox"/>			
	7.4.1l Lack of weather information	<input type="checkbox"/>			
	7.4.1m Other, specify.....	<input type="checkbox"/>			
PART VIII) LIVELIHOOD INCOME AND EXPENDITURE SURVEY (Wellbeing assessment)					

8.1 What source of income do you have & how much do you earn in (Birr) yearly?			
	8.1.1 On-farm income	8.1.1a from crops []	
		8.1.1b from livestock []	
		8.1.1c other sources, specify []	
	8.1.2 Off-farm income	8.1.2a Daily laborers []	
		8.1.2b Wages []	
		8.1.2c Investment []	
		8.1.2d other sources, specify []	
8.2 Do you make a pool of incomes of all earning members?	8.2a Yes []	8.2b No []	
8.3 If no, do you take share from each earning member to make a pool?	8.3a Yes []	8.3b No []	
8.4 If Yes, how much is the share in Birr?	[]	[]	
8.5 What types of animals do you own?	8.5a Cattle []	8.5d Pig []	
	8.5b Sheep []	8.5e Chicken []	
	8.5c Goat []	8.5f Equine []	
	8.5g Others, specify []		
8.6 On average how many of the above livestock do you have now?			
8.7 How many more have you acquired this year?			
8.8 On average how many did earn from selling (Birr)	[]	[]	
8.9 Do you seek for veterinary services for them?	8.9a Yes []	8.9b No []	
8.10 Which of the following asset is available at your home?	8.10a Cutlass []	8.10b Hoe []	
	8.10c Knapsack []	8.10d Radio []	
	8.10e Irrigation pump []	8.10f Mobile []	
	8.10g Television []	8.10h Bicycle []	
	8.10i Motorcycle []	8.10j Car []	
	8.10k Tractor []	8.10l House []	
	Other, specify.....		
8.11 Price of above assets if you were to sell it now (ETB)	[]	[]	
8.12 If you suddenly need money, where do you turn to?	[]	[]	
8.13 What is the average amount of money you can get from this source?	[]	[]	
8.14 What is the average amount of money you can get from this source?	[]	[]	
8.15 Do you source credit to finance your farm operations?	8.15a Yes []	8.15b No []	
8.16 Did you buy any input for credit during the 2020 season?	8.16a Yes []	8.16b No []	
8.17 If yes, what were the terms of the credit?	8.17a repay in cash []		
	8.17b repay with farm produce []		
	8.17c repay with cash and farm produce []		
	8.17d other, specify.....		
8.18 Did you repay with interest?	8.15a Yes []	8.15b No []	
8.19 If yes what was the interest rate?	[]	% []	

8.20 What is/are your HH expenditures look like (Birr)?	8.20a Food <input type="checkbox"/> 8.20b Health <input type="checkbox"/> 8.20c Clothing <input type="checkbox"/> 8.20d Education <input type="checkbox"/> 8.20e Weddings (Son, Daughter) <input type="checkbox"/> 8.20f Funerals <input type="checkbox"/> 8.20g Taxes <input type="checkbox"/> 8.20h Weddings of relatives <input type="checkbox"/> 8.20i Expenditures on legal matters like courts police station etc. <input type="checkbox"/> 8.20j Other major exp., specify.....
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Appendix 3: Tools used for food security measurement

a) Availability dimension - Household Consumption and Expenditure survey (HCES)

Household average dietary energy consumption per capita is an indicator that approximates calorie consumption based on the total amount of food acquisition or consumption by the household. Consuming an adequate number of calories is essential (but not sufficient) for proper growth, development, and cognitive and physical functioning. Household average per capita energy acquisition or consumption trends can provide early warnings of where there may be problems for population-level undernutrition or overweight/obesity for specific regions within a country or for the country as a whole (INDDEX Project, 2018).

To construct the indicator of HCES, the acquisition or consumption of each household reported will be converted into dietary energy (K/cals) by matching individuals' foods with food consumption table. The quantity of calories is computed by accounting the portion consumed or purchased, divided by the total household members (INDDEX Project, 2018). If the data will be collected over number of days, this calculation need to be divided by the number of collection days so as to generate the amount of calories/person/day.

b) Access dimension – Household Food Insecurity Access Scale (HFIAS)

No	Question	Response options	Code
1	In the past four weeks, did you worry that your household would not have enough food?	0= No (skip to Q2) 1=Yes	__
1a	How often did this happen?	1 = Rarely (once or twice in the past four weeks) 2 = Sometimes (three to ten times in the past four weeks)	__
2	In the past four weeks, were you or any household member not able to eat the kinds of foods you preferred because of a lack of resources?	0= No (skip to Q7) 1=Yes	__
2a	How often did this happen?	1= Rarely (once or twice in the past four weeks) 2= Sometimes (three to ten times in the past four weeks)	__
3	In the past four weeks, did you or any household member have to eat a limited variety of food due to a lack of resource?	0= No (skip to Q7) 1=Yes	__
3a	How often did this happen?	1= Rarely (once or twice in the past four weeks)	__

		2= Sometimes (three to ten times in the past four weeks)	
4	In the past four weeks, did you or any household member have to eat some foods that you really did not want to eat because of lack of resources to obtain other type of food?	0= No (skip to Q7) 1=Yes	__
4a	How often did this happen?	1= Rarely (once or twice in the past four weeks) 2= Sometimes (three to ten times in the past four weeks)	__
5	In the past four weeks, did you or any household member have to eat a smaller meal than you feel needed because there was no enough food?	0= No (skip to Q7) 1=Yes	__
5a	How often did this happen?	1= Rarely (once or twice in the past four weeks) 2= Sometimes (three to ten times in the past four weeks)	__
6	In the past four weeks, did you or any other household member have to eat fewer meals in a day because there was no enough food?	0= No (skip to Q7) 1=Yes	__
6a	How often did this happen?	1= Rarely (once or twice in the past four weeks) 2= Sometimes (three to ten times in the past four weeks)	__
7	In the past four weeks, was there ever no food to eat of any kind in your household because of lack of resource?	0= No (skip to Q8) 1=Yes	__
7a	How often did this happen?	1= Rarely (once or twice in the past four weeks) 2= Sometimes (three to ten times in the past four weeks)	__
8	In the past four weeks, did you or any household member go to sleep at night hungry because there was no enough food?	0= No (skip to Q9) 1=Yes	__
8a	How often did this happen?	1= Rarely (once or twice in the past four weeks) 2= Sometimes (three to ten times in the past four weeks)	__
9	In the past four weeks, did you or any household member go a whole day and night without eating anything because there was not enough food?	0= No (questionnaire finished) 1=Yes	__
9a	How often did this happen?	1= Rarely (once or twice in the past four weeks) 2= Sometimes (three to ten times in the past four weeks)	__

c) Utilization dimension – Food Consumption Score (FCS)

Food groups	Food items belonging to the group	Food groups	Weight
1. Cereals and grain	Rice, pasta, bread / cake and / or donuts, sorghum, millet, maize	1. Cereals	2
2. Roots and tubers	Potato, yam, cassava, sweet potato, taro and / or other tubers		
3. Legumes/nut	Beans, cowpeas, peanuts, lentils, nut, soy, pigeon pea and / or other nuts	2. Pulses	3
4. Orange vegetables	Carrot, red pepper, pumpkin, orange sweet potatoes,	3. Vegetables	1
5. Green leafy vegetables	Spinach, broccoli, amaranth and / or other dark green leaves, cassava leaves		
6. Other vegetables	Onion, tomatoes, cucumber, radishes, green beans, peas, lettuce, etc.		
7. Orange fruits	Mango, papaya, apricot, peach	4. Fruit	1
8. Other fruits	Banana, apple, lemon, tangerine		
9. Meat	Goat, beef, chicken, pork (meat in large quantities and not as a condiment)	5. Meat and fish	4
10. Liver, kidney, heart and/ or other organ meats			
11. Fish/Shellfish	Fish, including canned tuna, escargot, and / or other seafood		
12. Eggs			
13. Milk and other dairy products	Fresh milk / sour, yogurt, cheese, other dairy products	6. Milk	4
14. Oil/fat/butter	Vegetable oil, palm oil, shea butter, margarine, other fats / oil	7. Oil	0.5
15. Sugar, or sweet	Sugar, honey, jam, cakes, candy, cookies, pastries, cakes and other sweet (sugary drinks)	8. Sugar	0.5
<p>Steps of determining FCS as developed by WFP (2008)</p> <ol style="list-style-type: none"> 1. Group food items in the specified food groups (condiments not included) 2. Sum all the consumption frequencies of food items within the same group 3. Multiply the value of each food group by its weight (see table) 4. Sum the weighted food group scores to obtain FCS 5. Determine the household's food consumption status based on the following 6. Thresholds (WFP cut-off points): (0-21: poor; 21-35: borderline; >35: acceptable) 			

Appendix 4: Focus Group Discussion (FGD) questionnaire

Instructions to FDG facilitators/mediators

- Hold a group discussion with community elders and disadvantaged people. For each group hold discussions with the following groups separately: Men (20 years old +); Women (20 years old +); People with Special Needs (20 years old +).
- Selection of the participants should be guided by a local community leader/s but **not** influenced by them. As far as possible, the people in the group should represent the average households living in the village/neighborhood (i.e., neither the poorest of the poor, nor the most educated, well-off and influential people). If possible, try and gather a mix of people receiving assistance and people not receiving any assistance.
- Each discussion should not last for more than 1.5 hours, preferably 45mins to 1 hour.
- Local authorities and leaders should be kindly asked not to be present at these discussions, separate interviews can be arranged with them
- Inform participants that the aim of the discussion is to: assess their understanding about the concept of Climate-smart agriculture, *understand their current food security situation. It would also be important to see how people are making a living in the area for example the type of income generating activities they undertake. The information collected will help in understanding their overall food security situation sustainably.* .
- Inform participants that participation to the discussion is voluntary and no details (names and numbers) will be recorded.
- Be clear that participation in the meeting does not mean that assistance will automatically be delivered to this particular group, nor that participants will be targeted for support. However, the results will be used only for PhD study fulfilment.
- If appropriate ask participants to introduce themselves. However, emphasize that during the discussion they should not speak only on their own behalf, but should reflect the situation of the majority of households in the area as they know it.
- Start with two or three general questions to put people at ease, for example:

I will introduce myself and then I would like each of you to tell us your name, where you are from in Kaffa, when you arrived and whether you have participated in a similar discussion before.

I	Section 1 Preliminary (complete before the interview)	
A	Questionnaire code	
B	Interviewer name	
C	Date	
D	Zone	
E	Woreda	
F	Kebele	
G	Watershed	
H	GPS coordinate	
II	Overall food security situation	
2.1	What are the estimated number of the households in the area? [Report in number]	
2.2	What are the estimated number of female-headed households in the area?[Report in number]	
2.3	What are the Climate-smart agricultural practices being implemented? List out as follows: 1. 2.	

	3.	
2.4	<p>What are the three main staple food commodities consumed in the area/community? Answers may include any 3 staple items. Below are some examples :</p> <ol style="list-style-type: none"> 1. Kocho 2. Bread 3. Enjera 4. Rice etc 	
2.5	<p>On average how many meals do people now consume in a day? [Report in number]</p> <p>Has this number changed over the last 12 months? If so how and why?</p>	
2.6	<p>What are the 3 main sources of food in the area/community in the last 7 days? [Report from below list]</p> <ul style="list-style-type: none"> • Own production/garden • Casual labour/work • Borrowed • Gifts from friends/neighbours • Purchase from main shop • Food assistance • Purchase from roadside vendor • Hunting/gathering/catching 	
2.6	<p>What is the percent of people receiving WFP/SARC General Food Assistance in the village/town/area? [Use proportional piling if needed to calculate %]</p>	
2.7	<p>Has the number of people buying on credit increased compared to same time last year? Yes _____ No _____ If yes, by how much _____ %</p>	
2.8	<p>Out of typical household total food monthly expenditure, how much is bought on credit? _____ [% of total]</p>	
2.9	<p>On average how many households receive remittances on a monthly basis? _____ [% of total]</p>	
III	Coping strategies	
3.1.	<p>What proportion of households in this community have used coping strategy because they don't have enough food or enough money to buy food:</p>	<p>Question 1: Rely on less preferred and less expensive foods? _____ [Report one of the four options: 1. all of the households, 2. half of the households, 3.less than half, 4. none] Has this increased, decreased or remained the same compared to June 2020? _____ If increase or decrease kindly elaborate:</p> <p>Question 2: Borrow food, or rely on help from a friend or relative? _____ [Report one of the four options: 1. all of the households, 2. half of the households, 3.less than half, 4. none] Has this increased, decreased or remained the same compared to June 2020? _____ If increase or decrease kindly elaborate:</p> <p>Question 3 Purchase food on credit? _____ [Report one of the four options: 1. all of the households, 2. half of the households, 3.less than half, 4. none] Has this increased,</p>

		<p>decreased or remained the same compared to June 2020? ____ If increase or decrease kindly elaborate:</p> <p>Question 4 Limit portion size at mealtimes? _____ [Report one of the four options: 1. all of the households, 2. half of the households, 3.less than half, 4. none] Has this increased, decreased or remained the same compared to June 2020? ____ If increase or decrease kindly elaborate:</p> <p>Question 5: Restrict consumption by adults in order for small children to eat? _____ [Report one of the four options: 1. all of the households, 2. half of the households, 3.less than half, 4. none] Has this increased, decreased or remained the same compared to June 2020? ____ If increase or decrease kindly elaborate:</p> <p>Question 6: Reduce number of meals eaten in a day? _____ [Report one of the four options: 1. all of the households, 2. half of the households, 3.less than half, 4. none] Has this increased, decreased or remained the same compared to June 2020? ____ If increase or decrease kindly elaborate:</p> <p>Question 7: Skip entire days without eating? _____ [Report one of the four options: 1. all of the households, 2. half of the households, 3.less than half, 4. none] Has this increased, decreased or remained the same compared to June 2020? ____ If increase or decrease kindly elaborate:</p> <p>Question 8: Send household members to eat elsewhere? _____ [Report one of the four options: 1. all of the households, half of the households, 3.less than half, 4. none] Has this increased, decreased or remained the same compared to June 2020? ____ If increase or decrease kindly elaborate:</p>
3.2		<p>Question 1: Sold household assets/goods (radio, furniture, refrigerator, television, etc.) to purchase food? [Report one of the four options: 1. all of the households, 2. half of the households, 3.less than half, 4. none] Has this increased, What proportion of households in this community have decreased or remained the same compared to June 2020? ____ If increase or decrease kindly elaborate:</p> <p>Question 2: Sold productive assets or means of transport (sewing machine, wheelbarrow, bicycle, car, irrigation equipment, welding machine, livestock, etc.) to purchase food? _____ [Report one of the four options: 1. all of the households, 2. half of the households, 3.less than half, 4. none] Has this increased, decreased or remained the same compared to June 2020? ____ If increase or decrease kindly elaborate:</p> <p>Question 3: Withdrawn children from school because ‘you’ want to use money to buy food? _____ [Report one of the four options: 1. all of the households, 2. half of the households, 3.less than half, 4. none] Has this increased, decreased or remained the same compared to June 2020? ____ If increase or decrease kindly elaborate:</p>

	<p>What proportion of households in this community have decreased or remained the same compared to June 2020? ____ If increase or decrease kindly elaborate: used the following livelihood coping strategy because they do not have enough food or enough money to buy food:</p>	<p>Question 4: Reduced non-food expenses on health and education? ____ [Report one of the four options: 1. all of the households, 2. half of the households, 3. less than half, 4. none] Has this increased, decreased or remained the same compared to June 2020? ____ If increase or decrease kindly elaborate:</p>
		<p>Question 5: Spent savings? ____ [Report one of the four options: 1. all of the households, 2. half of the households, 3. less than half, 4. none] Has this increased, decreased or remained the same compared to June 2020? ____ If increase or decrease kindly elaborate:</p>
		<p>Question 6: Had any family member migrate? ____ [Report one of the four options: 1. all of the households, 2. half of the households, 3. less than half, 4. none] Has this increased, decreased or remained the same compared to June 2020? ____ If increase or decrease kindly elaborate:</p>
		<p>Question 7: Borrowed money/food from a formal lender/bank? ____ [Report one of the four options: 1. all of the households, 2. half of the households, 3. less than half, 4. none] Has this increased, decreased or remained the same compared to June 2020? ____ If increase or decrease kindly elaborate:</p>
		<p>Question 8: Sold last female animals? ____ [Report one of the four options: 1. all of the households, 2. half of the households, 3. less than half, 4. none] Has this increased, decreased or remained the same compared to June 2020? ____ If increase or decrease kindly elaborate:</p>
		<p>Question 9: Asked their children to sell chewing gum/tissues on the street (i.e. begging)? ____ [Report one of the four options: 1. all of the households, 2. half of the households, 3. less than half, 4. none] Has this increased, decreased or remained the same compared to June 2020? ____ If increase or decrease kindly elaborate:</p>
		<p>Question 13: Had their daughter/s married-off early (before 15 years old) to reduce mouths to feed in HH? ____ [Report one of the four options: 1. all of the households, 2. half of the households, 3. less than half, 4. None]</p>
3.2	<p>How do you evaluate the possible trade-offs and synergies in Climate smart agriculture?</p>	<p>Question 1. What practices exist that represent CSA in your area? ____ [How many households involve in this practice? Report one of the four options: 1. all of the households, 2. half of the households, 3. less than half, 4. none]</p> <p>Question 2: Are the communities aware in implementing CSA?</p> <p>Question 3: What significance did you notice out of implementing CSA practices?</p>

		Question 4: What trade-off exists in implementing CSA technologies?
		Question 5: What policy or institutional support exists in introducing CSA approach?
III	Household income	
3.1	<p>What are the main livelihoods activities undertaken in this area. Please provide percent the activity they mention contributes to their income.</p> <p>Answers may include:</p> <ul style="list-style-type: none"> • Cultivating & selling crops; • Trading commodities • Selling livestock • Selling livestock products (milk, cheese, butter, hides, meat, ghee, eggs etc.) • Charcoal burning • Selling timber • Employed • Other 	Details:
IV	Shocks and community priorities	
4.1	<p>What are the main 3 shocks for community/area in past 12 months (June 2018)?</p> <p>Answers may include:</p> <ul style="list-style-type: none"> • Drought/Floods/Erratic Climate • Conflict Intensification • Increasing prices (food, energy, etc.) • Etc. 	Details:
4.2	<p>What are the main 3 community/area priorities?</p> <p>Answers may include: •</p> <ul style="list-style-type: none"> • Access to water • Access to land • Education • Employment opportunities • Food Assistance • Non-Food Item Assistance • Etc 	Details:
Thank the participants for having taken part in the focus group discussion		
----- End of Focus Group Discussion -----		

Appendix 5: Key Informant Interview (KII) questionnaire

Target groups:

Local development agents, religious leaders, local political leaders, model farmers, NGO programme officers/coordinators and community leaders.

Objective:

These guide questions will help the researcher get an overview of the perceptions and practices of CSA and its associated impacts in food security and livelihood enhancement in Geshi Watershed. It is important to have such general information in order to situate the specific data collected from the FGD and HH survey questionnaire as well as who else could be interviewed in this regard.

Section I: Climate-Smart agriculture overview

1. How do you understand CSA?
2. Is there any practice associated with CSA in your farm/area? Mention if there is any?
3. Do you have any idea about climate change? Mitigation? Adaptation? Explain!
4. If there is any; what is the adaptive or mitigation measures being taken in your locality?

Section II: Benefits and constraints of CSA

1. What potential benefit does CSA have?
2. What are the possible constraints CSA could pose?

Section III: Impact of CSA on Food security

1. In your view, what is the food security situation of the community residing in this watershed?
2. Can you briefly describe/explain to us about malnutrition in this district/Kebele? What caused it?
3. Do you think the practice of CSA improved or deteriorated the food security situation of this area? Explain with examples
4. Do you have the capacity to feed your family the whole year with adequate access of food?
5. What is the trend of food production look like in your locality for 20 years to then?
6. If declining; what is the underlining factor to this effect?
7. What remedial measure is being taken from all stakeholders?
8. What tangible changes are being resulted?

Section IV: Impact of CSA on livelihood enhancement

1. What is the population density look like?
2. Is there enough access to land?
3. What are the major income sources to HH livings?
4. Is there any institutional setup in the locality that can support agricultural production and climate change mitigation efforts?
5. Is there enough access to agricultural inputs in the area?
6. Are there adequate credit facilities with reasonable interest and payback period in your area?
7. What policy gaps do you see in implementing CSA in your area in particular and the country as a whole?

If there is any idea missed or dare to explain with regard to CSA, its impacts in food security and wellbeing improvement in your locality, you can take time to explain.

Thank you for your time.

Appendix 6: Curriculum Vitae of Girma Tilahun

Girma Tilahun was born on November 12, 1981 (*Hidar* 03, 1974 Ethiopian Calendar) to a small business making household in Ethiopia, West Gojam Zone, Jabi-Tehnan Woreda, Jiga Town. He completed his primary education (1-8) in Jiga Primary and Secondary School in June 1997. Then, he attended and completed his secondary school education (9-12) in Damot Secondary School in June 2001. He, then, joined Hawasa University (the former Debub University), Wondogenet College of Forestry in October 2001 and after four years of study earned a BA degree in Forestry in July 2005.

After graduation, he was recruited as a junior soil and water conservation expert in the Agricultural Bureau of Tigray Regional State in August 2005. He then worked in different expertise and managerial positions until he was appointed as coordinator of water, mines and energy department of the Western Tigray Zone Growth Corridor in October 2008. In October 2011, he joined Mekelle University by winning the regional SIDA funded MSc degree scholarship competition. He specialized in Agroecology and Sustainable Development and earned his MSc from Mekelle University in June 2013 with a public open defense of the Master's thesis rated as "Excellent". He served as a lecturer in the University of Gondar, college of Agriculture of *Tseda* Campus from March 2014 to June 2017. In Gondar, besides teaching and research, he served as a chair of several small-scale University affair projects and committees. He joined Bonga University since August 2017 and is currently an academic staff there. In Bonga University, he served as a Department Head of Plant Science, Director of Strategic Partnership and Fund Raising Directorate and Delegate Vice president of Business and Development. He collected a number of national and institutional awards and certificates including a high level special Presidential award, best director award, best academic staff award, best event organizing committee chair award, participated in a number of University affairs committee as chair and member, University level research and community services for consecutive two years until he joined Addis Ababa University for his PhD study in October 2019.

Through the scholarship opportunity given to academic staffs in the nationally available institutions in Ethiopia by the Ministry of Education and Bonga University, he successfully passed the entrance examination and joined Addis Ababa University, College of Development Studies (CDS), Center for Food Security Studies (CFSS) in October 2019. His doctoral study focused on climate-smart agricultural science and its impact on food security and household welfare in Geshy watershed, Southwest Ethiopia.

Girma Tilahun is married to Maritu Dagnaw and has two siblings (one son and one daughter).