# AGROMETEOROLOGICAL INFORMATION ACCESS AND ADAPTATION TO CLIMATE VARIABILITY NEXUS: CASE OF SMALLHOLDER SORGHUM FARMERS IN BUSIA COUNTY, KENYA

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## DECLARATION AND RECOMMENDATION

**Declaration**

This thesis is my original work and has not been presented in this university or any other for the award of a degree.

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**Recommendation**

This thesis has been submitted with our approval as university supervisors.

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## DEDICATION

I dedicate it to my wife, Grace, mother, Judith, lecturers, and friends who have always invested their time and resources in me to enable me to pursue my education. Your love and support have kept me focused.

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## ABSTRACT

Significant losses among Kenyan farmers have been attributed to seasonal patterns and disruptions due to climate change. The provision of agrometeorological information as a countermeasure has been constrained by the accessibility and application of the information in adaptation to climate variability. This study aimed to improve the socio-economic welfare of smallholder sorghum farmers in Busia County by enhancing access to and application of agrometeorological information in climate risk mitigation. The study targeted small-scale farmers who are most vulnerable to climate variability and also focused on a traditional crop which has received limited attention in CSA studies. A multistage sampling technique was used to sample 423 smallholder sorghum farmers. Primary data was collected through face-to-face interviews using a pretested semi-structured questionnaire. A Multivariate Probit model was used to assess the factors influencing farmers' choice for agrometeorological information pathways. A binary logistic model was used to determine the influence of socio-economic, institutional, and climate-related factors on access to agrometeorological information. A Poisson regression method was used to evaluate the factors affecting the uptake of climate-smart agricultural practices. Finally, an Endogenous Switching Regression Model was used to assess the effect of agrometeorological information access, and socio-economic and institutional factors on adaptation to climate variability among smallholder sorghum farmers. The results indicate that sorghum farmers mostly used radio, television extension, and mobile internet as weather information pathways. Farmers were found to implement an average of 2 CSA practices. Literacy was associated with the use of television and mobile internet to access CSA information. Proximity to meteorological stations increases the probability of access to agrometeorological information by 8%. The use of Indigenous knowledge and trust in agrometeorological information increased the uptake of CSA practices by 0.119 and 0.229 units respectively. Failure to adapt CSA was associated with a lower sorghum yield with a projected mean decrease of 0.88 in yield. Similarly, adaption was associated with an income increase of 1.37. The findings of this study reveal the need for sensitizing sorghum farmers on the importance of adopting CSA practices such as drought-tolerant varieties, early maturing varieties, irrigation, water harvesting agroforestry among others to enhance their full-scale uptake, improve yield, and contribute to food and nutritional security. This can be enhanced through policies that strengthen agrometeorological information dissemination to small-scale farmers to enhance accessibility and applicability.

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| | |
|---|---|
| **AIC** | Akaike Information Criterion |
| **AWS** | Automatic Weather Stations |
| **BIC** | Bayesian Information Criterion |
| **CIPD** | Chartered institute of personnel and development |
| **CSA** | Climate Smart Agricultural |
| **DMC** | Drought Monitoring Centre |
| **GDP** | Gross Domestic Product |
| **ICT** | Information and Communication Technologies |
| **IPCC** | International Panel on Climate Change |
| **KMD** | Kenya Meteorological Department |
| **MVP** | Multivariate Probit |
| **NBR** | Negative Binomial Regression |
| **NEMA** | National Environment Management Authority |
| **PMT** | Protection Motivation Theory |
| **TAM** | Technology Acceptance Model |
| **SDGs** | Sustainable Development Goals |
| **SMS** | Short Media Messages |
| **SSA** | Sub-Saharan Africa |
| **TMA** | Tanzania Meteorological Authority |
| **WMO** | World Meteorological Organization |

# CHAPTER ONE

# INTRODUCTION

## 1.1 Background information

Climate change is a critical global issue with profound effects on agricultural productivity, which in turn impacts poverty and food security and jeopardizes the achievement of sustainable development goals (SDGs). Sub-Saharan Africa (SSA) is highly vulnerable to climate variability due to its geographic location, climatic conditions, dependence on agriculture and natural resources, and limited adaptation capabilities (Lemessa *et al*., 2019). The anticipated decrease in staple crop production, such as maize, millet, sorghum, and cassava, is expected to exacerbate these challenges (Reynolds *et al*., 2015). In Kenya, where agriculture is a major contributor to GDP and provides raw materials for local industries, climate variability leads to significant issues such as floods, droughts, and increased pest and disease occurrences (Muema *et al*., 2018). With the increasing frequency of extreme weather events, the importance of seasonal climate forecasting and early warning systems for effective planning and risk management in agriculture becomes even more critical (Gitonga *et al*., 2020).

It is essential for stakeholders to intensify their adaptation efforts to effectively mitigate the impacts of climate variability. Adapting to these changes requires making strategic adjustments to improve both preparedness and response to current and future climate challenges. A key component of this process is enhancing farmers' understanding of the risks and consequences associated with climate variability, which in turn helps them to better develop their adaptive capacity. Providing agrometeorological information plays a crucial role in this effort. Such information is fundamental for the adoption of climate-smart agricultural practices that aim to reduce vulnerability to climate change. By offering timely and relevant weather and climate data, agrometeorological services support smallholder farmers in managing the risks linked to climate variability. This, in turn, helps them make informed decisions, optimize resource use, and implement practices that are resilient to changing climatic conditions. (Vogel *et al.,* 2019). Agrometeorological information services have been expanding globally, with a significant emphasis from developed nations on supporting, funding, and enhancing capabilities in this field. This growth reflects a concerted effort to improve access to and the quality of agrometeorological data, thereby aiding agricultural planning and risk management in various regions (Suradhaniwar *et al.,* 2018). The World Meteorological Organization (WMO) has played a crucial role in fostering this growth and advancement.

Agrometeorological information can only be perceived as scientifically credible, reliable and legitimate if it is to be used in decision-making. The role of agrometeorological information in an environment where the main economic activity is dependent on rain-fed agriculture cannot be overstated (Gitonga *et al.,* 2020). Therefore, it should be packaged with accompanying context-specific advisory to assist the users in making economic decisions. Access to timely and relevant agrometeorological information is a necessary adaptation measure for agricultural production and risk mitigation (Muema *et al.,* 2018). The information influences farmers' decisions regarding land preparation, planting dates, and crop varieties to be planted and should therefore be accompanied by proposed pre-formulated strategies for adaptation. The government mainly provides agrometeorological information services in Kenya through the Kenya Meteorological Department (KMD). However, other government and non-governmental organizations (CBOs and NGOs) also support the KMD in providing information to farmers. The information is provided through newspapers, bulletins, radio, television, trained personnel/intermediaries, short media messages (SMS), and the internet. However, regardless of the efforts made, the impacts of climate variability have persistently affected the entire country, necessitating consideration of improved ways of combating the challenges posed by climate variability.

Timely agrometeorological information has the potential to help both governments and smallholder farmers cope with climate variability. Agrometeorological information helps smallholder farmers to know in advance whether the rainfall will be normal, below normal, or above normal. Rao *et al*. (2005) note that credible information helps smallholder farmers select appropriate crop varieties, modify their cropping practices, or implement other essential measures such as soil and water conservation strategies to mitigate the effects of climate change. Long-term climate change is likely to amplify the frequency and magnitude of extreme climatic events including floods and droughts. Therefore, there is a need for improvement in the dissemination of agrometeorological information because history becomes a less reliable guide in a changing climate environment (Oloo, 2013). This means that seasonal climate forecasts should have a more important role to play in the future. Most smallholder farmers are reluctant to adapt to improved strategies because they fear investing their scarce resources without having reliable agrometeorological forecasts that can guide them in their investment hence reducing these uncertainties (Serigne *et al*., 2006). Agrometeorological information plays a major role in climate change adaptation and more research is needed to produce information that can be tailored to specific localities, interpreted effectively, and properly communicated to various stakeholders

Climate-smart agricultural (CSA) practices are widely advocated as a key approach to addressing the impacts of climate variability in Kenya and other countries in Sub-Saharan

Africa (Kabubo-Mariara & Kabara, 2015). CSA aims to sustainably boost agricultural productivity and incomes by adapting to and enhancing resilience against climate change, while also reducing greenhouse gas emissions compared to traditional practices. According to Zougmoré *et al. (*2014) CSA practices are regarded as a key approach to achieving resilience while reducing environmental degradation. The CSA practices including agroforestry, carbon trading, raising awareness about rainwater harvesting and water management, crop diversification, and the adoption of drought- and pest-resistant crop varieties like cassava and sorghum, are considered essential for building resilience. Major stakeholders argue that implementing these CSA practices is crucial for ensuring food security for the anticipated 9 billion people by 2050.(Taylor, 2018). Boosted by its clarion call for change, CSA has become a key objective for international institutions and organizations working on addressing climate change phenomena with the context of enhancing agricultural development. For instance, the World Bank undertakes national-level CSA profiles to evaluate the present CSA effectiveness among developing countries such as the SSA and propose new places where CSA investment should be made (World Bank, 2015). Additionally, the World Bank has lauded the adoption of CSA practices as an essential technology for attaining sustainable development goals (SDGs).

The emergence of CSA has been remarkable with its impact on farmers in the wake of growing concern that climate change and its variability would constrain agricultural productivity and therefore need for a paradigm shift. Like FAO, CSA is a governance framework promoting the adoption of enhanced farming techniques. Within the highlighted context, CSA practices are more or less a set of parameters highlighting successful agricultural production models from the many existing heterogeneous normal farming practices. Some identified CSA practices could be classified as largely agroecological; For instance, water harvesting technology in India and farming-households managed tree regeneration within farms in Sahel (CGIAR,2013). Small-scale conservation agricultural production and industrial-scale mono-cropping are also classified as the leading CSA practices.

With the main agenda of CSA being to boost food production and stimulate economic growth, ineffective CSA targeting could constrain the achievement of the aforementioned goal, especially among small-scale farming communities (Mathews *et al*., 2018). CSA phenomenon is championed as a solution that could lead to high food production, livestock rearing, and environmental conservation and create a source of income among the rural poor. Therefore, CSA practices have to be tailored to achieve sustainable agriculture. Less focus has been directed on establishing proper infrastructure and engaging CSA technocrats with a clear understanding to implement CSA technologies effectively. Refocussing on the CSA approach could revive the potential sources for enhancing CSA adoption among small-scale farmers and boosting agricultural productivity. This is only possible if all the stakeholders synchronize their agenda by merging all the necessary CSA technologies with complementary effects while engaging the right personnel and ensuring infrastructure supports these phenomena (Azadi *et al.,* 2021).

Farmers have shifted their agricultural technologies to incorporate the changing climatic shocks and vulnerabilities, especially in developing countries such as the SSA countries. Currently, literature on climate change effects, its variability, and mitigation measures through adaptation and the use of CSA technologies continues growing and therefore CSA efforts must consider smallholder farmers in developing nations who play a crucial role in transforming the agricultural system. Additionally, policy support and financing for agricultural practices are important elements within the broader CSA framework. (FAO, 2013). This can be enhanced by CSA measures that include proven techniques, entail embracing new technologies, creating an enabling policy environment, and improving post-harvest handling of crop produce throughout the value chain to reduce losses, as well as promoting sustainable consumption patterns (World Bank, 2011; 2012). Agricultural activities are moving to integrate livestock and crop farming and strategic partnerships between farmers, meteorological departments, and extension service actors. These collaborations are crucial for forecasting, packaging, and disseminating agroweather information to target farmers effectively (FICCF, 2014). The reliability of weather forecasts can enhance the ability of farmers and the government to select appropriate crop varieties, modify cropping practices, initiate protective policies, and reduce uncertainties.

International attention to climate change phenomena has occasioned the formulation of many CSA action plans and initiatives, such as the Global Alliance for CSA (GACSA) and the African lead initiative called the Africa CSA Alliance (Mwongera *et al.*, 2017). Developing countries continue to grow nationally appropriate mitigation actions (NAMAs) alongside national adaptation programs of action (NAPA), underpinning the importance and need for farming systems capable of adapting to and withstanding the impacts of climate change. Despite the highlighted action plan, there is still a growing need for methods and techniques/practices that, on a larger platform, merge the socio-economic and biophysical situations across the board to prioritize, formulate, implement, and actualize CSA practices. Adopting CSA practices could be affected by institutional variables, land use policies, resource tenure, and economic, social, environmental, and climatic conditions. The context-specific aspect of CSA practices requires adopting diverse practices for various climate change shocks across the board to guarantee the effectiveness and efficiency of the CSA practices being implemented. For instance, Campbell *et al.* (2014) noted that resource-poor smallholder farming households in the least developed countries (LDCs) prefer farming systems that offer immediate benefits while enhancing agricultural productivity and adaptive capacity over CSA practices that increase carbon sequestration and reduce emissions. However, attaining the expected end goal of CSA practices is possible since the adaptive capacity of these technologies and mitigation are complementary rather than competitive.

Before implementation of CSA technologies in an area, resource mapping has to be conducted to delineate agro-ecological zones and understand the distribution of resources in the society, for example, forests, pastures, water sources including rivers, springs, streams, and lakes, among others, human residence and the available infrastructure (FAO, 2013). This is an uphill task that cannot be left to an individual to undertake. Therefore, it involves the multi-stakeholder approach by conducting a brainstorming exercise and general discussion for the various agroecological zones within the community (Mwongera *et al.*, 2017). The participants are then organized into groups based on their common farmlands (agroecological zones) and social identity within the prevailing and applicable context, such as gender, tribe/ethnicity, age, and size of farmland, among others. Another round of discussion precedes this activity to provide information on resource changes due to continuous use over time and propose communal action plans for future CSA practices investments.

Sorghum (*Sorghum bicolor (L.) Moench*) is among the important cereal crops utilized worldwide for human food, and animal feed and used as a raw material in commercial food industries and breweries (Timu *et al.,* 2014). It is the fifth most important crop in the world, with the United States of America (USA) being the highest producer, followed by India, Nigeria, and Mexico (Rao *et al.,* 2013). In Africa, sorghum is the second major crop after maize and is one of the main staple food crops in arid and semi-arid areas of Eastern and Southern Africa (Timu *et al.,* 2014). This is because it is drought-tolerant and can withstand periods of waterlogging (Muui *et al.,* 2013). In Kenya, sorghum is a traditional crop grown majorly by small-scale farmers, especially in the Arid and Semi-Arid Lands (ASALs) of the country. The crop had lost its preference due to the emergence of maize as the preferred staple food. However, due to the emergence of challenges caused by climate variability, compounded by the desire to stabilize food security in the country, there is renewed interest in promoting sorghum production. This is partly because sorghum is known to adapt well to harsh environmental conditions (Chepng'etich *et al.,* 2015). In addition, releasing the new sorghum lines suitable for brewing has encouraged farmers in Kenya to venture more into sorghum production for commercial purposes (Njuguna *et al.*, 2018).

Busia County in Kenya is taking proactive measures to address the challenges of climate variability by promoting the cultivation of drought-resistant crops like sorghum. This region, similar to other areas in Kenya, has been heavily impacted by changes in climate. In Busia, these effects are particularly severe, with significant repercussions for both crop and livestock production. As a result, the county experiences a notably high poverty rate of 64.2%, far exceeding the national average of 45.9% (GOK, 2010; Lukano, 2013). Research by Mugure (2017) highlights that local farmers in Busia have observed long-term alterations in temperature and rainfall patterns. These changes have led to consistently low agricultural productivity, driven by worsening soil fertility and an increase in extreme weather events. Historical data reveals that the frequency of droughts has escalated from occurring once every decade to every 2-5 years. This rise in drought frequency has led to severe consequences, including loss of biodiversity, increased soil erosion, and flooding. Additionally, unpredictable rainfall patterns have disrupted land preparation and food production, resulting in diminished crop yields across the board (Wekesa *et al*., 2018). Currently, sorghum is grown on approximately 13,109 hectares in Busia County. Despite its potential as a drought-tolerant crop, the average yield remains relatively low, at 1.3 metric tons per hectare (Omondi, 2019). These conditions underscore the urgent need for continued adaptation and support to enhance agricultural resilience and improve food security in the region.

Climate events in Busia County have significantly impacted both agriculture and local livelihoods. Farmers have observed a rise in droughts and floods, phenomena that were previously rare between the 1940s and 1990s. Notably, the drought that struck Teso North in 2016 led to widespread crop failures across the county, which in turn caused a surge in food prices. This price increase further strained the already high poverty levels in the region, making it difficult for many residents to afford essential food supplies. As such, environmental threats must be resolved to improve resilience due to these recurrent vulnerabilities. As a result, the County Government has attributed the below-average production of maize and other cereals to the early cessation of the long rains. Soil erosion, floods, and rainfall variability in rainfall patterns have been identified as the major challenges affecting land preparation and food production (Lukano, 2013). In collaborations with other organizations like the World Agroforestry Centre (ICRAF), National Environment Management Authority (NEMA) and Kenya Breweries, the County Government is advocating for the adoption of CSA strategies to address and manage climate variability. Thus, providing adequate agrometeorological information would help farmers make informed choices on varieties, inputs and other CSA (Mwadalu & Mwangi, 2013). Thus, this study examined how agrometeorological information affects adaptation to climate change and variability among sorghum farmers in Busia County.

### 1.2 Statement of the problem

According to the Global report on food crises, at least one in five Africans goes to bed hungry. FAO estimates 293.8 million to be severely food insecure in the sub-Saharan Africa region with 260.6 million being undernourished. The Central Bank of Kenya estimates the direct contribution of the agriculture sector to the Gross domestic product (GDP) at 22% and 27% indirectly through linkages with other sectors. According to the World Bank agriculture is the primary employer for over half of Kenya's workforce and plays a vital role in sustaining the livelihoods of 70% of rural households. However, the sector is heavily dependent on natural conditions for production and climate variability compounds the problem as it threatens local food production systems, compromising households' well-being due to persistent poverty, hunger, and malnutrition. In response, government agencies and non-governmental organizations provide agrometeorological information and promote programs geared towards cushioning farmers against climate variability. These collaborations have focused on drought-tolerant seeds, early maturing varieties, the introduction of modern farming techniques like irrigation, and water harvesting, and providing agrometeorological information through different pathways. This information is important to smallholder farmers in determining their vulnerability and resilience to the impacts of climate. However, the potential benefits of agrometeorological information can only be realized if they are accessible, accurate, and relevant for decision-making by farmers. Although the provision of agrometeorological information by the KMD and other providers has been promising, their access and application to manage climate risks are hindered by technical, social, economic, and psychological challenges, limiting benefits. It is unclear what factors influence smallholder sorghum farmers' choice for different pathways used in disseminating agrometeorological information. Furthermore, factors influencing the uptake of CSA practices and subsequent adaptation to climate variability remain unaccounted for. This study therefore, aimed to fill these knowledge gaps through an exploratory study among smallholder sorghum farmers in Busia County.

### 1.3 Objectives of the study

#### 1.3.1 General objective

The general objective of this study is to contribute to improved livelihood by enhancing response mechanisms to climatic variability through access and use of agrometeorological information among smallholder sorghum farmers in Busia County.

#### 1.3.2 Specific objectives

i. To assess the factors influencing the choice of agrometeorological information access pathways among smallholder sorghum farmers in Busia County.
ii. To determine the effect of socio-economic, institutional and climate-related factors on access to agrometeorological information among smallholder sorghum farmers in Busia County.
iii. To determine the factors influencing the uptake of CSA practices among smallholder sorghum farmers in Busia County.
iv. To evaluate the effect of adaptation to climate variability, agrometeorological information, and socioeconomic and institutional factors on agricultural productivity among sorghum farmers in Busia County.

### 1.4 Research questions

i. What factors influence the choice of agrometeorological information dissemination pathways among smallholder sorghum farmers in Busia County?
ii. What socio-economic, institutional, and climate factors influence access to agrometeorological information among smallholder sorghum farmers in Busia County?
iii. What factors affect the uptake of CSA practices among smallholder sorghum farmers in Busia County?
iv. What is the effect of adaptation to climate variability, agrometeorological information, and socioeconomic and institutional factors on agricultural productivity among sorghum farmers in Busia County?

### 1.5 Justification of the study

Human activities worldwide have shifted the ecosystem's normal behaviour to unpredictable levels. Industrialization, increase in human population, deforestation, and uncontrolled agricultural activities have polluted the environment, further putting the lives of future generations at risk. The highlighted challenges lead to climate change, a worldwide issue facing humanity with negative implications for agricultural activities. In this regard, poverty levels have been exacerbated alongside food and nutrition insecurity, threatening the realization of sustainable development goals (SDGs). Sub-Saharan Africa has been highly affected by climate change due to its high dependence on rain-fed agriculture, high poverty resulting in subsistence farming, and a limited ability to adapt to the challenges posed by climate variability. The situation is not different in Kenya, where farmers have suffered greatly from climate change variability, floods, drought, and an increased prevalence of pests and diseases.

Adaptation to climate change variability is therefore imperative to safeguard the current and future generations from these adverse effects and ensure the sustainability of human and animal lives in the ecosystem. This can only be enhanced by enhancing farmers' knowledge about climate variability's risks and challenges and boosting their adaptive capacity. One of the ways of improving farmers' awareness is through agrometeorological information services that ensure the adoption of climate-smart agricultural practices. These services promote resilience in farming activities worldwide and are offered by national governments, non-governmental organizations, research institutions, and other development partners. The importance of agrometeorological information services can only be realized if they are provided in time and packaged according to farmers' needs to assist them in making sound farming decisions.

Kenya, one of the SSA countries, relies heavily on rain-fed agriculture, leaving farmers particularly susceptible to climate variability because of the environment's fragility. To improve response strategies, timely and precise agrometeorological information is essential for adaptation efforts. Without effective adaptation and mitigation strategies, achieving and maintaining Sustainable Development Goals (SDGs) may become increasingly challenging beyond 2030. This research supports SDG 13, which underscores the critical need to address the impacts of climate change.

The County Government of Busia recognizes climate change as a significant challenge (Lukano, 2013). This study aids in achieving Busia County's integrated development plan and supports the County's strategic objectives by enhancing responses to climate variability, thereby improving farmers' resilience through adaptation strategies. Additionally, the findings provide valuable insights for policymakers and program designers regarding climate information systems in Busia County and at the national level.

## 1.6 Scope and limitation of the study

In this study, only smallholder farmers who have at most two hectares of land under sorghum and have been growing sorghum for at least three years in Busia County were considered. This is because the study is considering smallholder farmers; hence two hectares were ideal. Moreover, most of the effects of access to agrometeorological information such as the adoption of climate-smart agricultural practices, are felt after some time therefore we consider three years to be adequate for the impact of access to agrometeorological information to be felt. The study was limited to household and farm-level analysis; hence reliability and quality of the results depended on the respondent's ability to give honest information.

## 1.7 Operational definition of terms

**Agrometeorology:** Is an acronym for agricultural meteorology, a branch of meteorology concerned with applying meteorological information to agriculture.

**Climate:** Climate is most commonly described as "average weather" or "the statistical definition of appropriate quantities in terms of the mean and variability over time scales ranging from months to thousands or millions of years."

**Climate Smart Agricultural practices:** Agricultural practices that sustainably and effectively boost productivity and incomes (adaptation), cut or eliminate greenhouse gas emissions (mitigation), and support the attainment of national food security and development objectives

**Climate Change:** According to the United Nations, Climate change refers to long-term shifts in the average temperatures and weather patterns.

**Climate variability:** refers to time scales ranging from months to decades, falling between the extremes of daily weather and the long-term trends associated with climate change.

**Climate variability adaptation:** refers to adjustments in ecological-social-economic systems in response to actual or expected climatic stimuli, their effects or impacts

**Response to climate variability:** refers to the actions or activities undertaken by the farmer to curb, prevent, or minimize the effects of climate variability

**Smallholder farmer:** According to UNCTAD Smallholder farmers are defined as those farmers operating 2 ha or less for production and using part of the produce for family consumption**.** Therefore, in this study, a smallholder sorghum farmer is a farmer farming sorghum on less than 2 ha of land.

**Weather:** According to the World Meteorological Organization (WMO), is the state of the atmosphere at any given time or place. Wind, temperature, humidity, air pressure, cloudiness, and precipitation are all factors that influence the weather. The weather in most areas varies greatly from hour to hour, day to day, and season to season.

**Adaptation**: Adaptation refers to adjusting to actual or expected future climate to reduce risks from the harmful effects of climate change and make the most of any potential beneficial opportunities associated with climate change

**Farm size:** Refers the to the total land owned by the household including land where structures are constructed

**Farm Land:** Refers to the portion of land allocated to farming.

# CHAPTER TWO
# LITERATURE REVIEW

## 2.1 Introduction

This chapter provides a review of literature that is associated with the study either directly or indirectly. It encompasses literature on climate variability and change, impact of climate variability on sorghum production, agrometeorological services in Kenya, access and utilization of agrometeorological information, Factors affecting access to agrometeorological information, the various information dissemination pathways and packaging and dissemination of information. The section also explores challenges in determining the impact of agrometeorological information, different climate smart agricultural practices and their development in Kenya, the relationship between agrometeorological information and adoption of climate smart agricultural practices, and the socio-economic and institutional factors affecting the adoption of the climate smart agricultural practices. Moreover, the section also analyses the determinants of adaptation to climate variability and change, factors affecting the uptake of climate smart agricultural practices, and the effect of adaptation to climate variability on productivity. The chapter ends with a detail of the theories guiding the study which include the technology acceptance model (TAM), protection motivation theory (PMT), the utility maximization theory, and the conceptual frameworks guiding this study.

## 2.2 Climate variability and change

Climate change poses significant challenges to agricultural productivity, food security, and the overall development of rural households, particularly in Sub-Saharan Africa. Farmers in this region are especially vulnerable due to their heavy reliance on agriculture as their primary source of income and their limited ability to adapt to climate variability (Lemessa *et al.*, 2019). Extreme weather conditions such as prolonged droughts, persistent floods, rising temperatures, and heatwaves disrupt agricultural activities and threaten the livelihoods of farming communities by reducing their income from farming. Additionally, the unpredictability associated with climate variability can deter individuals from investing in farming as a viable economic activity (Asante & Amuakwa-Mensah, 2015). The interplay between global greenhouse gas emissions and natural climate variability means that the impacts of climate change are not uniform. Farmers' experiences with climate change can vary significantly depending on regional differences in the frequency and intensity of extreme weather events. This variation highlights the need for region-specific strategies to address the challenges posed by climate change and enhance agricultural resilience.

The aforementioned is evidenced by a decline in agricultural production of SSA's most important crops (staple foods) such as maize, millet, sorghum, and roots and tubers (Nuani *et al.,* 2022; Reynolds *et al.,* 2015). Within farming households, climate change results in extreme poverty due to the loss of income sources and exacerbates existing social imbalances (Carr & Thompson, 2014). Climate information services passed to farmers in a favorable environment allow them to understand risks, and anticipate, plan, and manage climate change (extreme events). This involves taking advantage of conducive climatic conditions, timely planting, and adapting to climate change through the implementation of various measures that reduce the hazards resulting from exposure to climate change effects.

Although concerns about global warming emerged decades earlier, the establishment of the Intergovernmental Panel on Climate Change (IPCC) in 1988 marked a significant effort by scientists to assess the extent of global warming caused by greenhouse gases (Penz, 2019). Their research confirmed that the climate system is warming, with the global average temperature increasing by 0.74°C (Smerdon, 2017). In the past century, Africa has experienced a temperature rise of 0.05°C per decade, closely aligning with global warming trends. Simulations from Africa's climate model project annual temperature increases of approximately 3°C to 4°C, which is about 1.5 times the global average rate, under various emission scenarios. (Nicholson, 2019). Its drier subtropical regions are expected to warm faster than the wet tropics, with precipitation anticipated to decline in the majority of the Mediterranean, North, and Southern African countries (Oguntunde & Abiodun, 2013).

Although nearly all models agree that the climate will warm, the precise extent of the warming is uncertain (Nicholson, 2019). On the other hand, rainfall is extremely erratic in both space and time (Penz, 2019). The average precipitation in East Africa is rising, and only a few areas are expected to experience a decline in average rainfall (Gebrechorkos *et al.,* 2019). Although this trend is unclear, King *et al.* (2021) suggest that climate models have most likely underestimated the effects of warming in the Indian Ocean while overestimating precipitation in East Africa. Nearly every general circulation model (GCM) places a much lower premium on tropical climate variability caused by processes such as El-Nino Southern Oscillation (ENSO) and terrain-atmosphere interactions. They argue that these interactions are critical for assessing Africa's climate variability (Sutton *et al.,* 2019)

The effects of climate change have significantly diminished agricultural production, which in turn has had a detrimental impact on livelihoods. Anyoha *et al*. (2013) assert that the food crisis largely stems from reduced agricultural yields, a consequence primarily driven by climate variability rather than other factors. The ongoing shifts in climate patterns are projected to further undermine agricultural productivity and economic growth (Nhemachena *et al.*, 2014). Climate variability is considered one of the greatest threats to global food security and sustainable livelihoods due to its profound impact on agricultural systems (IPCC, 2014). Increased temperatures, changes in rainfall patterns, and a rise in the frequency and intensity of extreme weather events such as floods and droughts are expected to continue affecting agricultural production significantly (Shiferaw *et al.*, 2014; Brida & Owiyo, 2013). These factors collectively contribute to a challenging environment for farming, exacerbating food security issues and threatening the sustainability of livelihoods worldwide.

Agriculture in Africa is particularly vulnerable to climate variability, which results in changes in temperature, humidity, and precipitation. These fluctuations have a profound effect on agricultural productivity and present a significant threat to food security across many developing countries. Addressing these challenges requires solutions that are both environmentally sustainable and tailored to the specific needs of the region (Arslan *et al.*, 2015; Juana *et al.*, 2013). The impact of climate variability on agriculture is evident in several ways, including fluctuations in moisture levels, increased prevalence of pests and diseases, reduced crop yields, and various weather-related hazards (IPCC, 2014). Extreme weather events, such as prolonged droughts and intense floods, are expected to affect global water availability, further compromising agricultural production. These changes underscore the need for adaptive strategies that can help mitigate the adverse effects of climate variability on agriculture and enhance food security.

Like many other countries in Sub-Saharan Africa that rely heavily on agriculture for their livelihoods, Kenya has faced significant challenges from extreme weather events. These include floods, droughts, variable precipitation, and increased occurrences of pests and diseases. Among these, drought has been the most prevalent issue, with 28 major droughts recorded over the past century (Gichangi *et al.*, 2015; World Bank, 2016). In response to these challenges, the Kenyan government has implemented several initiatives aimed at reducing vulnerability to climate risks and improving resilience and adaptation to climate change. Key initiatives include the National Climate Change Response Strategy (NCCRS), launched in 2010, which outlines strategies for managing climate change impacts. This was followed by the Kenya National Climate Change Action Plan (NCCAP 2013-2017), introduced in 2013, which provides a framework for climate adaptation and mitigation actions. Additionally, the Kenya Climate Smart Agriculture Project (KCSAP) was established to promote climate-resilient agricultural practices and enhance the capacity of farmers to adapt to changing climatic conditions. These efforts collectively aim to strengthen Kenya's resilience to climate variability and support sustainable agricultural development.

Kenya is experiencing climate change episodes evidenced by changes in rainfall patterns, floods, drought, increased prevalence of pests and diseases, and rising temperatures. Due to maritime and terrestrial influences, Kenya has diverse climatic conditions. When the average temperature varies according to elevation, the primary weather variation is in the amount of rain (Dalezios, 2017). Kenya's seasonal rainfall pattern is bimodal, with heavy rain occurring between March and June and light rain between September and November. Rainfall is directly proportional to topography, with the highest elevations in central mountain areas and some parts of the Rift Valley receiving 3200mm yearly. In contrast, regions with less than 500 mm of annual rainfall cover about two-thirds of Kenya. Climate change has led to increased variability in precipitation, particularly in arid and semi-arid areas, making rainfall patterns even more unpredictable in regions that typically receive higher amounts of precipitation (Agesa *et al*., 2019). Long-term climate data indicates that Kenya experiences both droughts and floods approximately every decade, with these events constituting 60% of all disasters in the country (Okayo *et al*., 2015). Despite the generally low rainfall in many areas, significant flooding still affects regions such as Lake Victoria, the Tana River basin, coastal areas, and parts of the semi-arid and arid zones. The impacts of human-induced climate change are likely to exacerbate these extreme weather events, potentially leading to even more severe consequences for Kenya's socioeconomic development and living conditions in the future (FAO, 2018).

The aforementioned effects are further exacerbated by overdependence on rain-fed agriculture which suffers during low rain seasons and low adaptive capacity to the climate variability among small-scale farmers. Climate change negatively impacts farming, food, and nutrition security in Kenya's arid and semi-arid regions (Kogo *et al.*, 2021). Key stakeholders have already identified climate change adaptation strategies, and their implementation is underway. However, the level and extent to which these climate adaptation strategies are known to farmers depend on the information dissemination pathways (Waaswa *et al.*, 2021). Enhanced investment in quality, relevant, and reliable climate-related information expands the horizon of the available options for making farmers, especially those practicing small-scale agriculture, more resilient and prosperous in the wake of climate risks. However, the targeted climate change information has to be packaged and relayed in a manner likely to address the specific challenges facing farmers in a given area in the wake of social inequalities within the farming communities (Gopalakrishnan *et al.*, 2019).

Although adaptation to climate variability can be used to understand variations among smallholder farmers, Burke and Lobell (2017) used a satellite-based assessment of yield variation among farmers to raise possibilities for monitoring and understanding agricultural productivity. The study found a correlation between satellite-based and traditional field-based yield estimates. It also detected positive yield responses to fertilizer and hybrid seed inputs. The study suggests that high-resolution imagery can be used to make forecasts of smallholder agricultural productivity that are roughly as exact as the survey-based measures traditionally used. In studying climate variability and change in North-Western Kenya, Opiyo (2014) sought to understand the effects and provide insights into pastoralists' risk management adaptations at the household level. The study looked at the responses of vegetation to precipitation anomalies in Turkana County, Kenya, and found high inter-annual rainfall variability with seasonal uncertainty. It also found that extreme events such as droughts have increased over the last 63 years, with 28.5% occurring between 1950 and 1970 and 47.9% experienced over the previous two decades. The study also observed that area temperatures have increased by about 0.13$^{o}$C, with a significant rise in both minimum 0.2$^{o}$C and maximum 0.1$^{o}$C temperatures from 1979-2012. Some of the adaptation strategies by community groups included vegetation shifts to more shrub bushland, favouring livestock diversification (browsers) such as goats and camels.

Dry spells, prolonged droughts, flooding, erratic rainfall patterns, changes in planting and harvesting dates, and increased temperatures are among the many ways climate change effects manifest themselves (Musafiri *et al.,* 2022). The effects of climate change have severe socioeconomic repercussions, such as crop failures and livestock losses. Challenges associated with climate change and variability include estimating the probability, severity, and length of occurrence. Farmers' vulnerability is eminent when reliable weather and climate information that supports adaptation to more resilient farming practices is unavailable. Available weather and climate information do not favour informed decision-making among farmers, such as time for land preparation, planting time, type of seed to be used, and the likelihood of severity of the weather (Onyango *et al.,* 2022). Multiple climate shocks such as floods, erratic rainfall, dry spells, and droughts have become common among farmers in western Kenya. Some of the strategies smallholder farmers adopt to overcome climate change's effects include climate-smart agricultural practices such as agroforestry, water conservation strategies, crop diversification, crop-livestock integration changing planting dates, growing early maturing crops, use of drought-tolerant crops, mulching, crop rotation, soil and water conservation, water harvesting, irrigation, intercropping, integrated soil fertility management, zero or minimum tillage, soil erosion management measures and timely planting.

Climate change and variability have adverse effects on agricultural productivity and food security systems. Elevated temperatures, droughts, flooding, and increased atmospheric temperatures all contribute to reduced crop productivity. Crops such as potatoes that are temperature sensitive perform poorly in scenarios of high temperature (Waaswa *et al.,* 2022). Extreme temperatures cause heat stress in crops, though warmer conditions can also accelerate the growth of certain crops such as melons, grapes, and tomatoes. Crops like maize, wheat, and potatoes have reduced yields in scenarios of high temperatures. Furthermore, pest and disease infestation occur mostly in areas where temperatures are high, leading to reduced productivity. Climate change is evident and affects dairy farmers who rely on rain-fed fodder production strategies. Increased environmental temperatures are linked to shifts in biome ranges resulting in livestock, fodder diseases, and pests that reduce productivity (Wetende *et al.,* 2018). Farmers perceive climate change as being responsible for reduced crop yield and crop failure hence they embrace diverse adaptation strategies to enhance their response to the effects of climate change and variability. (Kogo *et al.*, 2022).

**2.3 Climate variability and sorghum production among smallholder farmers**

Climate variability is mostly manifested through droughts, floods, increased temperatures, delayed onset of rains, and changes to normal weather patterns among others. The effects are far-reaching destroying plants, depleting soil fertility, reducing soil moisture, and destabilizing cropping cycles. Extreme weather events have become more common leading to a reduction in soil moisture, diminished soil fertility and waterlogging, which lead to severe water stress for plants. Frequent droughts lead to reduced pasture availability hence affecting livestock farmers adversely through the death of animals making them remain in the poverty trap. Drought leads to increased fertilizer needs due to decreased soil fertility caused by crop failure and lack of crop residues to revitalize the soils. The increased need for fertilizer increases production costs hence minimizing profitability for the farming households. It also affects the soils due to the increased use of chemical fertilizers which increases the soil acidity affecting the growth of subsequent crops. Floods cause soil erosion and waterlogging, disrupting nutrient release and leading to decreased soil fertility, which in turn reduces crop yields (Shongwe *et al*. 2014).

According to Tessema and Simane (2019) who investigated the possible impact of climate variability and transition on agriculture in the United States. They analyzed scenarios produced by two GCMs the Canadian Climate Centre (CCC) and the United Kingdom Meteorology Office (UKMO). By 2030, they expected a 17% increase in sorghum yields under the CCC scenario, despite a 4% decline in precipitation. They anticipated a 15% increase in sorghum yields and a 6% increase in precipitation under the UKMO scenario by 2030. Sorghum yields increased by 70% in 2090 under the CCC scenario, corresponding to a 17% increase in precipitation. A 23% increase in precipitation was predicted under the wetter scenario (UKMO). Rinaldi and Luca (2012) examined the impact of climate change on sorghum hay in Southern Italy using the Environmental Policy Integrated Climate (EPIC) model. Two future climate scenarios (A2 and B1) were extracted from three statistically downscaled GCMs, namely CCSM3, ECHAM, and HadCM3. For each GCM and scenario, three-time segments were run (2011-2040, 2041-2070, and 2071-2100). In both cases and for all three GCMs, the simulated results indicated that crop cycle length and biomass will be reduced. The A2 scenario's worsening trends were more prominent than the B1 scenarios and in the final time slice (2071-2100). The A2 scenario resulted in a 5 t ha-1 reduction in dry plant biomass and a 20-day increase in crop cycle length. The performance of the CCSM3 and HadCM3 versions was more comparable. However, there was no difference between the A2 and B1 climatic scenarios in the ECHAM model with sorghum yields increasing by 70% in 2090 as a result of increased precipitation.

Boomiraj *et al*. (2012) used a sensitivity analysis of India's temperature rise to simulate sorghum. A single climate change scenario (A2a) derived from HadCM3 model outputs was used for three-time slices in the 2020s, 2050s, and 2080s. The outputs of the three-time slices were then compared to the baseline conditions (1961-1990). The study discovered that a 1°C increase in temperature during the rainy season reduces sorghum yields by 4% to 8% in regions where sorghum is grown. Furthermore, a 2°C increase in temperature resulted in an 8% to 15% decrease in winter sorghum yields. The simulation results indicated that sorghum yields Sannagoudar *et al*. (2020) examined the impact of climate change on sorghum production in India. Four kharif sorghum genotypes viz, CSV-23, CSV-17, CSH-23, and CSH-16 were screened in a field experiment. These scenarios resulted in a decrease in sorghum biomass and yield during the rainy season in Akola and Hyderabad. Following the rainy season, there was a negligible increase in the yield of sorghum grown. Additionally, the study discovered that the growing season selected has a major impact on how sorghum responds to climate change. Traoré *et al.* (2021) found out that the main signs of the effect of climate change were erratic rainfall, major temperature changes, and the start of rainy seasons sooner. Sorghum yields were said to have dropped because of these effects. The duration of experience in sorghum production and the availability of labour providers within the household also influenced the choice of adaptation strategies employed.

Traoré *et al.* (2021) found out that the main signs of climate change impacts were erratic rainfall, major temperature changes, and the start of rainy seasons sooner. Sorghum yields were said to have dropped because of these effects. The number of years of sorghum production experience as well as the availability of labour providers in the household also influenced the type of adaptation strategies that were used by smallholder farmers. To improve sorghum production in the study areas, it is important to assess and optimize the agronomic efficacy of these coping strategies. Franke (2021), assessed the impact of climate change on crop production in Southern Africa. Despite their significance in southern Africa's climatic conditions, both the impact of heat stress on crop reproductive processes and transpiration cooling mechanisms, which mitigate heat stress, are underrepresented in models. Twenty reports on the effects of climate change on potential crop yields, mainly maize, have been published. Potato, Bambara groundnut, and sugarcane yields improved as a result of these findings. However, in maize and sorghum, there were no visible patterns. Although yield forecasts were inherently context-dependent, the significant uncertainties associated with climate projections and crop models necessitate caution when interpreting the findings.

## 2.4 Agrometeorological services in Kenya

Agrometeorological services were introduced in Kenya in 1974 to assist researchers in selecting appropriate plant and animal breeds for the sustainable food production system in the country (G. Masesi, 2019). The agrometeorological information and services also targeted the decision and policymakers with prerequisite information for conserving and managing natural resources. Initially, commercial farmers and government institutions such as Kenya Agricultural and Livestock Research Organizations (KARLO) were the main users of this information service. Due to climate change and variability, overcoming communication and technological barriers, access to agrometeorological information is becoming increasingly critical among smallholder farmers (Tarchiani *et al.*, 2021). This information is crucial as it helps farmers make informed decisions to manage the impacts of extreme weather events, including droughts, floods, seasonal changes, and outbreaks of pests and diseases. Some of the agrometeorological and information services provided by the Kenya Meteorological Department (KMD) include the start and end of the rainy seasons, the amount of rainfall expected (Barrett *et al.*, 2021), probable planting dates, forecast on weather and crop performance, advisory on the adverse effects of the weather on crops, advisory services on harvest and post-harvest operations.

Until the end of the 1980s, the Kenya Meteorological Department operated a dense network of over 2,500 observation stations, most of which were rainfall stations (Valizadeh & Bijani, 2020). However, the network has been slowly dwindling since 1990, and there are now less than 1000 observing stations. The department operates a network of 32 Synoptic stations, 13 of which provide agricultural meteorological statistics, crop phenology, and soil moisture data in addition to other meteorological data, while the remaining stations collect data on climate (Dahlin *et al.,* 2020). Technological advances and the widespread use of information and communication technologies (ICT) have resulted in the automation of weather observation instruments and facilities, such as automated weather stations (Kaňovská, 2021). The Kenya Meteorological Department is phasing out manual instruments in favour of these Automatic weather stations (AWS), with over 24 AWS already installed. Data on crop variety, stage of growth, crop production, plant density, and soil moisture are collected at 13 agrometeorological stations. Expected yields are usually determined at the end of every ten days and communicated to the agrometeorological section, along with meteorological data, to aid in the assessment of crop-weather effects (Rogers & Tsirkunov, 2013). Through visual inspection and oral interviews with farmers, all 32 stations provide reports on crop growth stages, production levels, and expected yields to offer a comprehensive overview of crop performance nationwide, particularly for key staple foods like maize, beans, and wheat.

Agro-advice and timely alerts are becoming invaluable, particularly in the agricultural sector. Agrometeorological services provide necessary information to the national economy's agriculture and food security sectors. The agricultural sector relies entirely on weather patterns, especially in Kenya, where a considerable percentage of the yield variations are weather-dependent (Tarchiani *et al.*, 2021). Farming requires an ambient environment a reliable mixture of sun, warmth, wind, and rain for optimal production. As a result, customized and tailored, accurate weather forecasts are essential for farm production. Farming management services that are translated into weather information can be passed as messages for agricultural planning. These services support farmers in making the right and timely decisions for farm management. The agrometeorological information services inform farmers of the suitability of the weather for specific activities, such as planting, fertilizing, and harvesting. In addition, accurate agrometeorological information with local precision can form a crucial link to enable small-scale farmers to become climate-smart and change-resilient. With the advancement of technology and telecommunication infrastructure penetration, farmers can easily access localized and personalized information.

### 2.4.1 Access and utilization of agrometeorological information in Kenya

Agrometeorological services, which are part of weather and climate services, play a significant role in supporting SSA agriculture, which faces a myriad of challenges (Tarchiani *et al.,* 2021). These services remain inaccessible to smallholder farmers, and their utilization is still low if they are available. Furthermore, they are not relevant to support decision-making among the users as an average of 46.7% of farmers use the agrometeorological information to decide on the types of crops to grow (Zendera *et al.,* 2010). While national meteorological agencies in African countries play an important role in generating and disseminating agrometeorological information, they heavily depend on global data sets. This is supplemented by the coordination support offered by regional hubs including the Intergovernmental Authority on Development Climate Prediction and Application Centre (ICPAC), the Agrometeorology, Hydrology, Meteorology (AGRHYMET) Regional Centre, and the Southern African Development Community Climate Services Centre (SADC-CSC).

ICPAC supports early warning systems by disseminating climate hazard information to East African countries, AGRHYMET supports in the provision of food security and environmental information in West Africa while SADC-CSC provides operational services for climate monitoring, predict extreme events and provide hydrometeorological products to Southern and Central African countries (Singh *et al*., 2017). AGRHYMET has introduced additional services including impact assessment of climate change to take care of the increased prevalence of extreme events (Traore *et al*., (2014). The regional hubs play a significant role in providing seasonal forecasts at the regional scale, creating networking opportunities for engagement between scientists and users of agrometeorological information, and supporting the improvement of human resource capacity in regional climate modelling, prediction, and application. This has led to more engagements between national climate agencies in Africa with climate modelling institutions in developed countries increasing the production of long-term climate projections (Sigh *et al*., 2018)

In Kenya, there are many sources of agro-meteorological information including the National Meteorological Centre in Nairobi, where farmers access information through radio and television, Kenya Agricultural Research and Livestock Organisation (KARLO), extension officers, the Internet and the Drought Monitoring Centre (DMC). Technological advancements have led to the revolutionization of access to agrometeorological information leading to increased use of mobile phones in delivering agrometeorological information and advisory services to rural farmers. To ensure access to this information, a greater understanding is required regarding access to these gadgets and the types of services available on these digital platforms. For instance, Krell *et al.* (2021) indicate that owning a personal smartphone increases the likelihood of accessing m-services.

The rising frequency and intensity of extreme events like droughts and floods have led to greater demand for agrometeorological information among smallholder farmers (Sivakumar, 2021). Access to this information will help smallholder farmers cope more efficiently with climate variability, improve their resilience, and minimize losses in agricultural production (Oyugi & Tembe, 2016). The government of Kenya (GoK) and other stakeholders have made significant efforts to collect the agrometeorological information, analysis, archiving, and making it accessible for the benefit of the farmers (Ozor & Nyambane, 2018). However, accessing and using the information among the smallholder farmers in Kenya remains a challenge. Some of the challenges include communication barriers, inadequate interaction with the user communities to assess the appropriate dissemination procedure, poverty levels among the users, and lack of knowledge regarding the significance of this information, etc.

Many studies have examined the significance of accessing agrometeorological information among smallholder farmers. For instance, Krell *et al.* (2021) indicate that mobile phone use among smallholder farmers in central Kenya can help them access information that helps them manage and reduce vulnerabilities to climate change. The study further indicates that access to agrometeorological information is critical to agricultural productivity, mainly reducing uncertainty and risks associated with extreme weather events. Access to dependable and relevant agrometeorological information among farmers in rural areas enables them to make strategic and tactical decisions in agricultural management. Some of the benefits highlighted include a 40% reduction in production costs and a 41% increase in income (Tarchiani *et al.,* 2021).

Larger access to radio has made it to be the most convenient way of accessing agrometeorological information. In their study Agyekum *et al*. (2022), found out that radio was the most common means of accessing weather information with mobile phone (text messages and voice calls), television, and extension officers also being used. According to Zendera *et al.* (2010), in a study that focused on smallholder agriculture irrigation farmers and how they accessed and utilized agro-meteorological knowledge to spur farming, 98.1% of farmers possessed a radio, and 90.4% could listen to it daily to access weather information services. Other dissemination channels included television, neighbours, newspapers, extensions, and *barazas.* The study also reveals that the least popular dissemination channels include mobile, internet, and bulletins. Further, a study by Tarchiani *et al.* (2021) alludes that in rural areas, radios remain the main information channel for farmers, followed by extension services and local social networks. Other channels, such as mobile phones and social media, are gaining momentum, but their usage is still poor. Issues of trust (credibility and accuracy) of the agrometeorological information services also determined the source of information.

## 2.5 Factors affecting access to agrometeorological information

While agrometeorological information is a valuable resource for weather-informed crop management in the Sahel (Bacci *et al.,* 2020), farmers still face several constraints in accessing and utilizing the information (Ahmed & Kiester, 2021; Antwi-Agyei *et al.,* 2021; Ofuoku & Obiazi, 2021). Some of the constraints include farmers' socioeconomic attributes such as level of education, household size, farm size, extension contact, and membership in farmers' associations. According to Antwi-Agyei *et al.* (2021), access to climate information is influenced by both household and environmental factors. The dissemination process can encounter many challenges, such as a lack of access to the internet, difficulties in understanding technical terms, and information delays, access to resources, cost of information, channel of dissemination among others. However, well-established knowledge dissemination channels and networks are feasible options to allow feedback from end users. Moreover, timely dissemination of weather information is key as information that is not delivered on time does not serve the intended purpose. A study by Ofuoku and Obiazi (2021) examined the constraints to access and utilization of meteorological services in Delta State, Nigeria. The study found that the major constraint to accessing agrometeorological information was the untimely release and transmission of information and this was highly correlated with the dissemination channel.

The cost of accessing information is also a major factor that may determine if a farmer gets access to information. The majority of farmers are capital-constrained and would allocate the little capital they have on inputs and activities that go directly into the farm as opposed to accessing information. When examining factors influencing access to and willingness to pay for climate information services Antwi-Agyei *et al.* (2021), found that most farmers were not willing to pay for the cost of receiving information. The study further indicates that several factors, such as drought, food insecurity, and farming experience, influenced accessibility to climate information. They also suggest that the provision of climate information should be customized to meet the smallholder farmer's needs considering their adaptive capacity.

Mobile phones are regarded as platforms that can reach the majority of farmers in developing countries. There has been increased connectivity, ownership of mobile phones, reduced connectivity fees, and access to mobile handsets, promoting mobile-based services to access agrometeorological information among smallholder farmers (Krell *et al.,* 2021).

Although accessing agrometeorological information through mobile-based services can improve agricultural livelihoods, there are glaring disparities, especially among the rural poor. It has been observed that wealthier, more educated, and urban populations have greater access to m-services compared to rural people. Some of the significant challenges highlighted include the cost of airtime, faulty handsets, type of mobile phone used, language barrier, and unfriendly user services and language barrier. In his study Nyantakyi-Frimpong (2019) notes that information delivery channels should always be appropriate regarding farmers' age, literacy level, gender, and social status to enhance accessibility and utilization.

Access to agrometeorological information services exhibits gender-based differences. For instance, women’s ability to access agro-meteorological information is enhanced when the services and dissemination channels are located within the village where most of their chores, such as childcare and daily household activities, are located (Gumucio *et al.,* 2020). Access to group processes, information, and communication technologies can limit women from accessing agrometeorological information. Sociocultural norms favouring men in labour roles and access to resources contribute significantly to women not accessing agrometeorological information. The findings of Diouf *et al.* (2019) support for this observation, highlighting that men generally have greater access to climate information services compared to women. Their study, which explored the impact of gender on access to climate information among farmers in Senegal, uncovered significant gender-based disparities. Specifically, the research found that women, who make up 95% of those seeking climate information, predominantly request details about the onset of rainfall. This suggests that women’s information needs are often more focused on immediate, practical aspects of weather patterns, reflecting broader gender differences in access to and utilization of climate-related information.

Inadequate information on the existence of a weather station was cited as a major reason farmers could not access agrometeorological information (Keinembabazi, 2022). Other cited factors include the inadequacy of knowledge to make meaningful decisions, the hard-to-understand language used in the bulletins, and the time for weather information broadcast. Similar findings were noted by Gumucio *et al*. (2019) who found that farmers who were exposed to Rwanda Climate Services for Agriculture interventions were able to access weather information through multiple channels as compared to those who did not have the information. The study also found that women farmers who participated in trainings or Farmer Listeners’ Clubs were accessing and using information more significantly than women who did not participate directly in the interventions. According to Antwi-Agyei *et al*. (2021) note that the majority of small-scale farmers had received inadequate information on seasonal forecasts for long-term planning and this was a key barrier to their ability to access and utilize climate information.

In assessing factors affecting awareness, access, and utilization of agro-climate services, Buckland and Campbell (2021), found gender, age, access to extension services, group participation, climate change perceptions, non-farm income, farm size, and agronomic conditions had an influence. Further, active use of the climate and weather information was correlated with farmers' experimental observation of the relevance of the information and the immediate use. The study indicates a gap between awareness of climate information services and using the information in decision-making. The highest awareness and access were through TV/Radio. Age was influenced significantly in accessing climate information services as older farmers appeared to have higher access but preferred to stick to only one service compared to younger ones who preferred more than one CIS (Buckland & Campbell, 2021). Older members were also more likely to be members of farmers' groups where most extension farmers rely on climate information, exposing them to more climate information. Thus, this makes them access more information compared to their younger counterparts. This study also looked at the issues of age and how they influence access to agrometeorological information to see whether these findings contradict or corroborate.

Agricultural production is a risky enterprise; hence lack of accurate information services for smallholder farmers can be cited as a major impediment to accessing agrometeorological information. Hence, smallholder farmers prefer daily forecasts through radio channels as they can do proper planning. According to Zendera *et al.* (2011), inadequate extension services (72%) were cited as the major factor affecting access and utilization of agrometeorological services. Other factors affecting farmers' adoption of agrometeorological information included inaccurate weather forecasts, inadequate agrometeorological information for meaningful decision making, and the delay in releasing seasonal forecasts giving farmers less time to make preparations. Findings by Antwi-Agyei *et al*. (2021) emphasize that lack of trust can hinder access to climate information and is highly attributed to past experiences of smallholder farmers relating to inaccurate predictions. However, other literature has found contrary findings. For instance, Hassanpour and Ardekani (2019) found that most farmers believed in agrometeorological information. The information was effective in terms of determining planting and harvesting dates, use of insurance services, pest and disease control, and required planting material, hence improving their crop yields.

The low access, knowledge level, and use of agro-weather information are the major factors contributing to delays in forecasts leading to poor access to information. In their study, Wafula *et al.* (2016) found that limited outreach (23.4%), limited skill and knowledge (11%), and low utilization (8.1%) of agro-weather information was experienced among small-scale farmers. The exclusion of small-scale farmers from existing information and knowledge systems also restricts their access to agrometeorological data. Inadequate information delivery mechanisms, including issues with reliability, timing, infrastructure development, and language barriers, have further hindered access to agrometeorological information. Furthermore, inadequate and quality agrometeorological and agronomic data limit agricultural extension offices from interpreting weather data. These findings corroborate those of Murgor (2015) who indicates that poor coordination of agrometeorological information impaired the sharing and dissemination of this information. Additionally, Antwi-Agyei *et al*. (2021) conclude that information forecast should be communicated in local language so that it is easily understood and appreciated by smallholder farmers.

Most farmers are experiencing low access to supportive climate and weather information, with most of them incurring losses due to climate variability. Despite farmers gaining a lot of experience practicing their farm enterprises over time, access to agrometeorological information is critical. Farmers with indigenous knowledge on understanding rainfall indicators influenced their activities, forming a more significant portion of the source of climate and weather information (Murgor *et al.*, 2018). Agricultural Extension Officers and fellow farmers were the major sources of climate information accounting for 46.2 and 50 percent, respectively. Murgor (2015) also indicated that more than half of the studied farmers in Uasin Gishu County sourced their climate information from extension officers and fellow farmers. He further acknowledges that indigenous knowledge systems (planting and harvesting dates) were applicable for decision-making among maize and wheat farmers. The study recommended repackaging weather and agrometeorological information in customized formats will enhance ownership and sustainability.

The age of the farmers is an important factor in the access to agrometeorological information (Antwi-Agyei *et al.*, 2021). Older farmers are less likely to access information than young ones because younger farmers are more proactive, aggressive, and conversant with new technologies for accessing information through the internet. Older farmers may also rely so much on indigenous knowledge that they have acquired over time and hence may not see the need to access new information. Antwi-Agyei *et al*. (2021) and Muema *et al*. (2018), suggest that older farmers are less likely to seek agrometeorological information because of the vast climate knowledge they have gathered for many years. Furthermore, older farmers have indigenous climate monitoring and risk spreading skills hence less demand for accessing climate information services. Older farmers allude to confidence in knowing the weather patterns and do not see the need to seek agrometeorological information. For instance, in the study by Nesheim *et al.* (2017), a farmer argues that with 40 years in farming, they are already well conversant with the agricultural calendar and do not require more information.

### 2.6 Agrometeorological information dissemination pathways

Agrometeorological information pathways deal with distributing weather and climate information related to crop and livestock production and soil management. This information determines the success or failure of farming practices among agricultural producers by providing them with agro-meteorological information (Krell *et al.,* 2021). However, a deeper understanding of agrometeorological information dissemination pathways available to farmers and possible factors affecting their use is needed. Pathways such as radio, television, and mobile phones are touted as technological platforms with transformative potential to reach the majority of rural farming households (World Bank, 2018). The costs of mobile phones, radio, and television have fallen, and connectivity spread across regions which is highly beneficial to the poor farming communities. Through these information dissemination pathways, farmers access agro-meteorological and market information by listening to the radio, watching TV and google services using internet platforms (mobile phones, computers), and extension officers. Moreover, mobile phones can be used to deliver electronic information through short message service (SMS), unstructured supplementary service data (USSD), mobile applications (apps), and helplines through phone calls (Baumüller, 2018).

To address the impacts of climate variability and change, smallholder farmers in Lower Eastern Kenya view adaptation through agrometeorological information as a key solution (Onyango, 2021). The study explored the methods by which farmers in this region access agro-advisories. The results reveal that information communication technologies and face-to-face interactions are the preferred dissemination methods for many smallholder farmers seeking agrometeorological advisory services. With the high penetration of mobile phones, farmers nowadays can access timely information regarding agrometeorological information. Mobile phones are one pathway to managing risk and vulnerabilities in a changing climate. A study by Krell (2021) intimates that poor mobile communication networks, technological inequities, and inadequate awareness about mobile phone-based services pose a major hurdle to accessing and utilizing agrometeorological information. The study investigated how climate variability impacted small-scale farming systems and information communication technologies' role in diffusing digital-based information. The findings indicate that although most farmers owned a mobile phone, the overall percentage of adoption of mobile phone services for agriculture was low. The study suggested that leveraging farmer groups is a potential avenue for spreading digital information. As one of the dissemination pathways (mobile phones) considered, the study ascertained whether they play a role in accessing agrometeorological information for agricultural purposes

Rural farmers in developing countries depend on radio broadcasts for timely agrometeorological advice at their local levels (Tarchiani *et al.*, 2017). To encourage the use of rural radio for transmitting advice to farmers, the WMO, FAO, and the Technical Centre for Agricultural and Rural Cooperation (CTA) convened a meeting in 1992 in Bamako (Mali) on the use of rural radio for transmitting advice to farmers. Another way of disseminating information is through 'agrometeorological bulletins.' The majority of these bulletins currently contain only meteorological data. Agricultural data is frequently gathered through interviews with farmers, especially when the agro meteorologist is located a great distance from the monitored region. This type of field data is extremely valuable for various purposes, including evaluating the predictions produced by crop simulation models and reporting crop conditions to central bodies. Some information dissemination pathways are free to use, while others may require cost to acquire advanced information. The choice of agrometeorological information pathway depends on the individual farmers' perception concerning whether the pathway improves agricultural livelihoods, accessibility of the pathway, the cost of using a given pathway, and ease of interacting with the pathway to acquire information (Wyche & Steinfield, 2016).

A study by Salla (2019) indicated that some dissemination pathways offer uncertain information which can affect the choice used by smallholder farmers. Some of the major reliable sources of weather and climate information identified by the study were human-based sources such as chiefs' baraza, agricultural extension officers, and social networks such as neighbours and farmer's groups offering seasonal forecasts and guidance on suitable crop types and agricultural counselling. These agrometeorological information pathways are essential in decision-making by farmers in meeting their agricultural production needs. However, some barriers limit farmers from using some of the pathways to access agrometeorological information. A study by Raj *et al.* (2020) indicates that smallholder farmers, particularly women, have limited access to climate information and the capacity to translate the forecast into suitable agricultural advisories. Most agrometeorological dissemination pathways do not consider gender needs when communicating agro-advisories, thus, limiting women from utilization.

In assessing the access to and use of seasonal climate forecasts among households in Masinga Sub-County, Masesi (2019) looked at several agrometeorological dissemination pathways. These pathways included radio, television, bulletins, extension officers, and chiefs' *baraza*. His findings indicated that most respondents (82%) used television and radio to access climate information services. Those who used bulletin as a dissemination pathway suggest that most of them used complicated language, while chiefs *baraza* were considered to use simple language. Inadequate agricultural extension officers were also a major limitation to accessing agrometeorological information. Over 60% of the respondents indicated that much of the information obtained from the dissemination channel was inaccurate, affecting the adoption of agro-advisories among smallholder farmers. The timing of agrometeorological information broadcasts also negatively impacted the dissemination pathway farmers used as most broadcasts were done during the day when most of them were in the field. To address these knowledge gaps, this study looked at the factors that influenced the choice and how many pathways smallholder farmers used as a source for agrometeorological information services.

While existing literature has explored the various pathways through which agrometeorological information is disseminated (Fay Buckland & Campbell, 2021; Gumucio *et al*., 2020; Onyango *et al*., 2021), there has been limited focus on understanding how farmers choose among these pathways, either as complements or substitutes, and the factors that influence their decision-making. To address this gap, the current study investigates the determinants affecting sorghum farmers' selection of agrometeorological information pathways. It examines a range of influencing factors, including socio-economic conditions, institutional contexts, topographical features, and characteristics of climate variability. The insights gained from this study are expected to contribute to the development of effective policy measures aimed at climate change adaptation, with a particular focus on enhancing the agricultural practices of small-scale sorghum farmers, who are among the most vulnerable in the region.

## 2.7 Packaging and dissemination of agrometeorological information

Increased population, high food demand, high poverty levels, and inadequate policies impact farmers' adaptation and coping capacities. Agrometeorological information that forms part of weather and climate services is vital in supporting agriculture in SSA, facing climate change and variability (Tarchiani *et al.,* 2021). Proper dissemination and access to agrometeorological information will improve the farmers' resilience and coping capabilities and eventually improve their livelihoods. Furthermore, agrometeorological information can help guide adaptation practices to address the impacts of climate change, farm management, and decision-making to improve farm productivity. Agrometeorological data represent one end of a continuum; scientific knowledge and comprehension represent the opposite. Additionally, this spectrum encompasses data analysis and information transformation. Information is useful when disseminated in such a way that it benefits end users the most (Dwivedi, 2018).

Agrometeorological data can be thought of as a vital component of modern farming. Farmers are also aware of the significance and value of experience. Numerous farmers in developing countries also pay for information on various topics, including weather forecasts, soil, and nutrient status assessments, pest management reports and recommendations, and advice on the best genetic seed line to plant for particular field conditions (Dey *et al.,* 2019). Farmers should consider the cost of information in terms of cost per hectare so that they can balance the anticipated benefits of information acquisition against the costs associated with implementing a recommendation. A technology that provides farmers with information at a cost greater than the recommendation's cost has a slim chance of widespread adoption.

Recurrent droughts and unpredictable rains increase farmers' vulnerability to climate change risks and their variabilities. Climate information services (CIS) is a mainstream strategy for mitigation against climate shocks either traditional knowledge systems or modern meteorological information enables farmers to receive timely information concerning weather patterns, including rainfall distribution, intensity, and frequency; wind storms; and droughts, allowing them to plan their farming activities more effectively and efficiently (Wanders & Wood, 2018). Important agricultural production decisions such as when to begin land preparation, when to arrow the land and plant, choice of the correct crop variety, fertilizer schedules, and herbicide and pesticide application are all linked to obtaining timely and seasonal forecast information. Literature on the adoption of CIS is limited for most SSA countries; therefore, it is essential to involve all stakeholders in the agricultural sector, including research institutions and the media, to ensure that farmers receive timely access to agro-advisory information services. This would allow farming households to interpret the information received by adopting the most suitable CSA technology based on their need and prevailing local circumstances. CIS information is often passed to farmers through mobile phones, radio, TVs, internet, and roadside advertisements, especially during the market days in rural areas and farmer open days (Etwire *et al.,* 2017).

Agrometeorological knowledge must be considered, as its timely availability and proper application are critical to farming operations' success. To qualify as a resource, this knowledge must demonstrate value to farmers and the numerous agencies supporting its development, generation, and dissemination. The benefits of agrometeorological knowledge must be communicated to all potential users in farming communities, especially in developing countries with low agricultural output and widespread food insecurity. Access to agrometeorological data and dissemination of new technologies is critical to optimizing adoption, particularly for 'knowledge-based' innovations (Gopal & Chintala, 2020). Since the target population is diverse, the content of agrometeorological information cannot be standardized. Knowledge can include the following, depending on its intended use: early warning advice to avert famine crises; agricultural planning policies; national climate policies in response to the Kyoto Protocol on climate change; special advisories given to farmers by the national extension service; and general advisories obtained directly by farmers. This information is very crucial for production as it has been demonstrated that information outlets, rather than subsidies, foster adoption by increasing smallholder farmers' capacity to allocate capital and revising their perceptions about the new technology's profitability (Frey, 2019; Ncube, 2020).

Due to the knowledge-intensive nature of agrometeorological information, its potential for uptake, especially among smallholder farmers, will be limited unless appropriate dissemination mechanisms are used to ensure its effective transfer. The dissemination of agrometeorological information must be optimized, considering the form of advice required and the end user's requirements. Farmers may obtain critical agrometeorological information from extension services or the news media. Farmer's knowledge ensures agrometeorological information is synthesized and used in decision-making. Therefore, a farmer may need guidance in addition to that normally given through agrometeorological services. This guidance is available via local extension or specialist consulting services or can be accessed for a fee if current patterns continue (Vogel *et al.*, 2017). Multiple transmission pathways will likely result in a range of choices among smallholder farmers for individual or concurrent pathways. While it is critical to understand smallholder farmers' information choices to evaluate the effectiveness and efficiency of dissemination pathways, it has been demonstrated that sources and methods of information communication should be chosen not only for their effectiveness and capacity to reach a large number of farmers but also for their perceived credibility and relevance (Nidumolu *et al.*, 2020; Nyasimi *et al.*, 2017).

According to Stigter (2004), agrometeorological and climatological data can be used to directly increase or safeguard agricultural production (yield quality, quantity, and income derived from yields) while preventing the degradation of the agricultural resource base. One type of agro-meteorological support is the establishment of measures to lessen the effects and minimize the effects of weather and climate-related natural disasters on agricultural production. Another form of agrometeorological service is monitoring and early warning exercises directly linked to already in place agricultural production-related measures. This will help to lessen the effects of weather and climate-related natural catastrophes on farm productivity. For agricultural and associated industries, numerous sources provide climate projections and forecasts as well as meteorological forecasts on various time scales, from years to seasons. A competent agrometeorological service is not always a good climate prediction. The target groups' capacity for acquisition matters greatly in addition to the forecaster's talents. This is demonstrated in the case study that follows (Lemos *et al.,* 2002).

Farmers rely on climate and weather information for on-farm decision-making, which is obtained from government meteorological agencies (Chengula & Nyambo, 2017). Agrometeorological services should include developing and disseminating climate forecasts supporting various agricultural activities. Weather and climate information services (WCIS) are the main entity from generation to dissemination and utilization of the information playing a significant role in agricultural production in developing countries (Salla, 2019). A link between agricultural production and WCIS has continually been embraced, with many African countries providing monthly and seasonal weather forecasts, agrometeorological information, and extreme weather warnings. The study by Salla (2019) further indicates that many areas still experience a lack of information systems that could help plan their agricultural activities and to build resilience against climate change. The study suggests that technology-based dissemination pathways, such as daily forecasts through the radio, do not offer useful information for the farmers due to high uncertainty. Despite farmers owning radios, they do not regularly access weather forecasts since they lack interest in the information, inadequate and inconvenient time slots allocated for broadcasting the information and poverty limits farmers from buying batteries for radios.

Efficient agrometeorological information services should entail the provision of information packaged with advice for proposed interventions for offsetting uncertainties that constrain farm decision making against climate risks (World Bank, 2016). With the advancement in technology, the provision of agrometeorological information (IPCC, 2013) has integrated scientific information into decision-making (Adams *et al*., 2015). In the face of changing climate and high vulnerability to climate risks (Hewitson *et al.*, 2014), developing countries must consider long-term planning decisions regarding future climate projections to help reduce risks and utilize opportunities. For agrometeorological information to be relevant, scientists should ensure that the information provided is tailor-made and reliable to be used by farmers in decision making (Daron *et al*., 2015). Several factors will influence the relevance of agrometeorological information received by smallholder farmers including; the nature of the prevailing risks, economic sector of focus, focus region, and governance structures among other context-specific realities including socio-cultural factors (Goddard *et al*., 2010).

### 2.7.1 Challenges in determining the impact of agrometeorological information

The ability of farmers who depend on rain-fed agriculture to utilize short-term agrometeorological information in managing climate risks is important in building towards the management of future risks. However, challenges revolving around relevance, provision, and usability result in minimal information on long-term agrometeorological information which informs decision making (Nidumolu *et al*., 2016). In the recent past, there has been a greater improvement in the utilization of agrometeorological information (Jones *et al*., 2015) but since this information is mostly disseminated in isolation from other factors like agronomic, economic, and social, it is often disconnected from real life making agricultural decisions difficult (Manjula & Rengalakshmi, 2015). It is also important to understand that barriers to access to agrometeorological information may differ from barriers to utilization of the information and both need to be addressed for agrometeorological information to be effective. Access is affected by social factors including gaps in integrating Indigenous knowledge, historical data, and processes to promote the interpretation of agrometeorological information (Dorward *et al*., 2015; Haigh *et al*., 2015). On the other hand, the utilization of agrometeorological information is influenced by the interaction between information producers and users as well as the usefulness of the information in decision making (Dorward *et al*., 2016).

To promote access and utilization of agrometeorological information, it is important to promote sensitization programs among the potential users demonstrating the utility of the information (Haigh *et al*., 2015) and participatory interpretation of information showing direct links with livelihood outcomes, timing of information delivery as most smallholder farmers focus on short time horizons in their decision-making cycles (Lobo *et al*., 2017). This is in recognition that decision making among smallholder farmers is a complex process influenced by sociocultural environmental, institutional, and governance factors (Singh *et al*., 2016). For agrometeorological information to be relevant in decision making, decision makers including farmers and policymakers must receive reliable information that can be trusted and in understandable forms (Mase & Prokopy, 2014), the information needs to be tailored toward specific regions to address local needs (Lobo *et al*., 2017), proper institutional and governance structures should be put in place to support provision of agrometeorological information (Vaughan & Dessai, 2014) and the socio-economic value resulting from utilization of the information in decision making should be clear (Dorward *et al*., 2015). Moreover, information should be generated through multi-stakeholder participatory approaches to support interpretation and enhance the direct economic utility for the end users to improve local resonance and increase uptake (Singh, 2017).

One of the challenges in determining the impact of agrometeorological services is establishing a benchmark against which to measure the impact. This is because climate is variable making it difficult to establish a valid baseline from which you can isolate changes resulting from the delivery and use of agrometeorological information from those resulting from normal climatic variation (Tall *et al.*, 2018). This indicates that changes observed may be a result of variable climate phenomena e.g. variation in rain or temperature conditions relative to the baseline year rather than the use of agrometeorological information in decision making. This calls for the use of long-term data over a long period to establish an appropriate climate baseline for the given region. However, long-term data is usually not available, especially in Sub-Saharan African countries presenting challenges in assessing the before and after effects. Moreover, the impact of agrometeorological information can only be accurately measured during poor or good rainfall years. During normal rainfall years, it is difficult to assess the impact because most farmers may not change their behaviour from what they normally do. This makes the availability of agrometeorological information lack statistical significance from lack of it. This supports the fact that using two reference points might be misleading especially if the two reference points are normal years it may imply that the forecast had no value for farmers. This situation is supported by Roudier *et al*. (2012) who retaliated that in normal years, there are less powerful strategies that can be found hence farmers use strategies that they could have applied without agrometeorological information.

Another challenge associated with measuring the effectiveness of agrometeorological information is the difficulty in isolating the impact of agrometeorological information use from the impact of other socio-cultural, economic, and political drivers of rural livelihood outcomes. For example, conflicts, cultural beliefs, or a farmer's ability to access government services e.g. subsidized fertilizer are all exogenous factors that can have a significant impact on farmer behaviour, yields, and income. This calls for the need of evaluators to establish the extent to which using climate information influences decision-making (Msangi *et al*., 2006). This is because the benefit from agrometeorological information may interact with other factors, making them synergistic hence making it difficult to isolate the effect of agrometeorological information intervention. Farmer decision-making is complex and may be based on agrometeorological information use or social and cultural factors. For example, Roudier *et al.* (2014) found that 75% of the farmers had embraced changes in their practices due to the introduction of seasonal forecasts. This leaves 25% who either did not embrace changes or embraced changes due to the effects of other factors. Therefore, identifying the impacts resulting from the use of agrometeorological information in decision-making presents a major challenge.

For agrometeorological information to be effective in decision making, it should be timely, reliable, easy to understand, and disseminated through the right channel. However, most of the time, agrometeorological information is not delivered timely, is unreliable, presented in formats that are not universally understood, and passed through pathways that are not universally accessible (*Carr et al*., 2015). These factors limit the effectiveness of the information hence difficult to measure impact (Tall *et al*., 2014). This is compounded by the fact that trust in information is associated with a high level of accuracy which is not always fulfilled as agrometeorological information is inherently characterized by some degree of uncertainty, and therefore may not always unfold exactly as predicted. Most African countries are still developing and have limited and outdated weather station infrastructure due to poor maintenance resulting from a lack of resources which greatly affects the quality of forecasts. (Mason *et al*., 2015). Africa is still below the World Meteorological Organization's standards in terms of standards and density of weather stations with only one-eighth of the required density and less than three hundred weather stations that meet the observation standards (World Bank, 2017). This is exacerbated by a lack of complete historical data which greatly affects the quality of information produced hence affecting the usefulness and value of the information consumers. Moreover, despite improvements in forecasting methodologies, the accuracy of agrometeorological information remains a big challenge (Dinku *et al*., 2016). This has the potential of causing harmful consequences on farmers' livelihoods hence affecting the general economic growth.

It is also crucial to recognize the value of indigenous knowledge, which includes the skills and practices developed by smallholder farmers over time through accumulated experience, societal interactions with nature, and community traditions and institutions. (Kniveton *et al*., 2014). This should be combined with scientific agrometeorological information which encompasses processed data and evidence-based knowledge about climatic conditions and is typically produced and disseminated by scientific institutions. The absence of reliable historical data, which is essential for understanding current climatic conditions, assessing climate models, and forecasting future climate projections, hampers the adoption and use of agrometeorological information. (Taylor *et al*., 2012). There is also the challenge of socio-cognitive constraints (Singh *et al*., 2016), poor governance systems or inadequate institutional capacity to effectively deliver and use climate information (Tall *et al*., 2014), and asymmetrical information flow between the producers and users of the information leading to distortion (Singh *et al*., 2016).

Historical data helps in understanding past and present-day climate risks. IPCC in its fifth Assessment Report used three observational data sets to develop a time series of global mean annual temperatures from 1850 to the present day (Stocker *et al*., 2013). In addition, historical data is also important as it is key in the development of the General Circulation Models (GCMs) which are used in climate prediction by assimilating observations to create spatially consistent data. GCMs are the primary source of future agrometeorological information and many national meteorological agencies have formed strategic partnerships with scientific institutions that provide global agrometeorological forecasts, based on GCM output (Signh *et al*., 2017) Advancement in technology has led to a dramatic improvement in the dissemination of climate information due to increased availability of climate data on online data portals which have become an important mode of communication (Daron *et al*., 2015). There are several online platforms supported by different organizations to disseminate agrometeorological information including; Climate System Analysis Group climate, Royal Netherlands Meteorological Institute (KNMI), the World Bank climate data portal, and the Potsdam Institute climate impacts platform. This development has led to agrometeorological information being translated into more user-friendly formats for ease of understanding and dissemination through innovative channels for more widespread uptake, ensuring quality, consistency, and appropriateness of the information (Dorward, 2015).

Insufficient engagement with decision makers hinders monitoring and assessing the use of long-term agrometeorological information in Africa. Moreover, most African countries have yet to integrate agrometeorological information into national development planning processes (Giorgis, 2011). This makes it difficult to understand how information is being used because of the increased gaps that exist between the information held in scientific institutions and that which is required by farmers and policymakers to inform decision making (Waagsaether & Ziervogel, 2011). While there is a great improvement in terms of coverage, quality, and advanced long-term forecasting skills by the scientific community (Hou *et al*., 2014; Hoskins, 2013), the utilization of agrometeorological information in decision-making is hampered by numerous scientific and practical barriers. The major barrier is the local relevance of agrometeorological information which is essential if the information is to be used in decision making. This calls for the translation of agrometeorological information at larger spatial scales into variables and processes that matter to end users, such as implications for local water supplies, floods, drought, rainfall amounts, etc.  However, this does not necessitate the need for high spatial resolution model data because the baseline climate of two nearby locations may but the range of projected climate changes could be the same at both locations (Bunyan *et al.*, 2015).

**2.8 Climate smart agricultural practices**

Climate variability presents significant challenges worldwide, with developing nations being especially vulnerable due to their dependence on rain-fed agriculture, limited capacity for adaptation, and heavy reliance on climate-sensitive agricultural practices. In East Africa, this issue is particularly pronounced, as climate variability has severely affected the agricultural sector, and projections suggest that these impacts will likely become more severe in the future (Aryal *et al.*, 2021). In Kenya, the effects of climate variability are increasingly evident. The country has experienced a rise in extreme weather events, including more frequent and intense droughts and floods. Additionally, there has been a noticeable increase in average temperatures and a growing unpredictability in rainfall patterns. These shifts have led to significant economic repercussions, with past instances of drought, such as those between 1999 and 2000, causing estimated damages equivalent to 2.4% of the Gross Domestic Product (GDP) (GOK, 2010). The growing frequency and severity of these climatic events underscore the urgent need for effective climate adaptation strategies to mitigate their impact on the country's economy and agricultural sector.

Agriculture is of paramount importance in Kenya, particularly for smallholder farmers in rural areas. It serves as a primary source of livelihood for many people living in these regions and plays a significant role in the country’s economy, contributing notably to the gross domestic product (GDP). Specifically, the agricultural sector directly accounts for approximately 33 percent of Kenya's GDP, and it contributes an additional 27 percent indirectly through its linkages with other sectors (FAO, 2019; Kogo *et al.*, 2021). Despite its critical role, smallholder farmers in Kenya predominantly rely on rain-fed crop production systems that are plagued by low productivity. These systems are highly susceptible to climate risks such as prolonged droughts, erratic rainfall patterns, and minimal use of agricultural inputs. Such climate-related challenges not only threaten the viability of the agricultural sector but also jeopardize livelihoods and contribute to escalating food insecurity. In response to these pressing issues, the Kenyan government has been actively developing strategies and policies aimed at mitigating the adverse effects of climate change. The focus is on enhancing resilience, increasing agricultural productivity, and promoting sustainability. A significant initiative in this regard is the Kenya Climate Smart Agriculture Strategy, which was collaboratively launched by the Ministry of Agriculture, Livestock, Fisheries, and Irrigation and the Ministry of Environment (Faling, 2020). This strategy aims to transform agricultural practices to better address climate change impacts and achieve goals such as improved food security and sustainable agricultural development.

With the global population anticipated to reach 9 billion by 2050 and the impacts of climate change becoming increasingly severe, there is a heightened urgency to improve agricultural practices to meet the growing food demands. Intensification of agriculture, however, often leads to several adverse environmental effects. These include increased deforestation as additional land is cleared for farming and the excessive use of agricultural chemicals such as fertilizers, herbicides, and pesticides, which contribute significantly to greenhouse gas (GHG) emissions. Given that farmers' primary focus is on boosting agricultural productivity to satisfy market demands, policymakers face the challenge of finding a balanced approach that both enhances food production and conserves the ecosystem. This balancing act is crucial for ensuring the long-term health and sustainability of agricultural practices (Williams *et al*., 2015).

Efforts to mitigate the effects of climate change on agriculture, especially for small-scale farmers, have highlighted the importance of innovation and greater access to technical knowledge and practices (Barth & Melin, 2018). In response to climate change and variability, various best practices have been developed to address these challenges (Tumushabe, 2018). Among the most recent and widely endorsed approaches is Climate Smart Agriculture (CSA). This concept, introduced by the Food and Agriculture Organization (FAO) and supported by major international organizations such as the International Fund for Agricultural Development (IFAD), the World Bank, the United Nations Environment Programme (UNEP), the World Food Programme (WFP), and the Consultative Group for International Agricultural Research/Climate Change Agriculture and Food Security (CGIAR/CCAFS), aims to achieve multiple objectives (FAO, 2019). CSA seeks to promote sustainable agricultural intensification, effective management of natural resources, and secure funding mechanisms for climate change adaptation. It also focuses on improving the livelihoods of small-scale farmers by enhancing their access to critical infrastructure, information, genetic resources, financial capital, and markets (Lopez-Ridaura *et al*., 2018). The goal of CSA is to boost productivity and return on investment while also improving livelihoods, increasing ecosystem adaptability, and reducing greenhouse gas emissions (Chandra *et al*., 2018). Under this definition, agriculture is considered "SMART" if it effectively meets these objectives, thus contributing to a more resilient and sustainable agricultural system.

The definition of Climate Smart Agriculture (CSA) provided by the FAO in 2010 is widely accepted among agricultural sector players and development experts globally. Nonetheless, there remains some confusion regarding which technologies and practices should be classified as CSA and which of the three pillars productivity, adaptation, or mitigation should be prioritized. Farming practices can vary significantly depending on the agroecological zones in which they are implemented, adding to the complexity of defining CSA. Researchers and CSA experts emphasize the importance of aligning CSA practices with agricultural policies and rural development strategies to ensure their effectiveness. Policymakers must develop a nuanced understanding of context-specific CSA practices that not only enhance agricultural productivity but also bolster resilience to climate change impacts (Partey *et al*., 2018). CSA practices typically involve several key components, including capacity building, promoting sustainability in farming systems, reducing greenhouse gas emissions, enhancing productivity, increasing profitability from farm commodities, and fostering innovation related to climate change impacts (Engel & Muller, 2016).

The CSA approach encompasses a range of technical, policy, and investment activities aimed at achieving sustainable agriculture and ensuring food security amid climate change challenges. It addresses all facets of sustainable agricultural practices, including agricultural development and management, as well as socio-economic and institutional changes. The CSA framework operates on three core pillars: achieving high agricultural productivity in a sustainable manner, adapting to and building resilience against climate change, and reducing greenhouse gas emissions whenever possible. Agricultural production practices that align with CSA principles contribute to lowering greenhouse gas emissions, such as carbon dioxide, while ensuring high productivity and profitability. These practices also help reduce vulnerability to climate change effects and enhance overall resilience (Lipper *et al*., 2014). By integrating these aspects, CSA aims to transform agriculture into a more sustainable and climate-resilient system.

Several climate change adaptation measures are concerned with land use change alongside a change in output patterns for attaining food security. Using organic fertilizers and practicing crop rotation reduces the pile-up of nitrogen gas emissions. Therefore, the CSA approach provides enabling tools where several agricultural technologies and activities could be assessed for their impacts aligned with their expected contributions to national growth and development, while also achieving food security objectives amidst climate change challenges. Additionally, the CSA approach champions the use of low-income farming practices like conservation agriculture that entails agroecology, ecosystem services, small-scale irrigation, agroforestry, aquaculture, soil water conservation, and minimum tillage and breeds (Chandra *et al.,* 2018). Most of these CSA practices have been tried and promoted in several countries of Africa, as evidenced in the literature, and include but are not limited to; the use of an integrated soil fertility management plan (use of a combination of organic and controlled industrial fertilizer) to increase corn production in the SSA (Gram *et al.*, 2020), Kenya included (Paul *et al.,* 2020).

Irrespective of its main agenda (solving challenges associated with climate change), the CSA framework maintains critical elements from the established policies. Inefficient incentives for agricultural intensification reduced agricultural productivity, environmental degradation, and shocks. Policy reforms aligning farmers' decisions with the prevailing market needs provide a win-win situation, increasing efficiency and sustainability (Taylor, 2018). Moreover, competition among farmers is likely to influence them to adopt modern farming technologies such as the CSA practices, resulting in higher yields from the same land and water endowments. Strict property rights are formulated to apportion rewards and externalities to stakeholders, combining market governance structures, technological development, and economic growth (World Bank, 2007). In this regard, market liberalization provides a platform for sustainable economic growth such that failure to suitably transform agriculture and modernize it might cause environmental degradation and push farming households into poverty traps.

To understand how CSA practices, affect farming activities, the World Bank built CSA country profiles that evaluated each country's agricultural productivity and identified the nations that have effectively moved in a climate-smart direction. The aforementioned World Bank metrics are meant to assess where further progress needs to be acted upon on a country-by-country basis. Additionally, the profiles look at the adoption of CSA practices among rural households that rely on agriculture as a significant economic activity. All these profile items are then rated on a scale of 1-5 depending on their magnitude of smartness in the context of water usage, carbon, nitrogen, and energy, among others. The higher the CSA practice score, the higher the agricultural improvement compared to conventional farming practices. Lower scores reveal a lack of progress attributed to the selected CSA technology (World Bank, 2015).

Using scaling indicators "Climate-smartness" to rank CSA practices and taxonomist them into a single list enables the attainment of a smart climate agenda. Therefore, the World Bank foresees a situation where it could likely promote public and private investment in areas where change has not been forthcoming while at the same time formulating CSA ideas and generating effective technological practices for adoption (World Bank, 2015). In this regard, CSA practices have received a shot from the private sector, who have backed the technology and formed a climate-smart agriculture working group headed by corporate organizations such as PepsiCo, Monsanto, Olam, as well as Kellogg Company. The World Bank understands that some agroecological techniques are necessary for sustainable food systems, especially in developing countries such as the SSA region, where agricultural intensification has degraded the ecosystem (Méndez *et al.*, 2015). CSA technology is broadly concerned with how food is farmed by focusing on field-level activities where external climatic problems and socio-economic issues affect the range and type of possible solutions. The highlighted concept allows the policy process to narrow down to only effective and efficient CSA technologies from a pool of existing practices among farming households.

A study by FICCF revealed that, many stakeholders supported the elevation of underutilized adaptive crops, such as sorghum and cassava, to major staple crop status (FICCF, 2014). Additionally, they recommended the adoption and strengthening of soil and water conservation practices, such as terracing and mulching, as these methods can significantly enhance soil water retention and alleviate the adverse effects of dry spells. (Oloo, 2013). FAO (2013) explained that enhancing rainwater storage in the soil through conservation tillage can help mitigate the negative impacts of drought. This approach necessitates the recycling of wastewater, desalinization, pollution control, improved access to and management of conventional water resources, habitat restoration, and pollution management. Agroforestry was also a key recommendation made in the FICCF meeting as an emerging and promising strategy that has the potential to improve and sustain agricultural productivity thereby enhancing farmer incomes in a changing climate. This concur with Kwesiga *et al*. (2003) who notes that agroforestry systems, which involve rotating fast-growing leguminous trees and shrubs with cereal crops to boost yields, are a vital strategy for enhancing soil fertility. These systems also provide fodder for animals, create a favourable micro-climate for crops, reduce heat stress, and supply fruits and wood for fuel and construction.

The significance of socio-economic and gender factors underscores the empowerment gap between men and women, as observed by successful stories of integrating gender agenda in the CSA approaches (Barasa *et al.*, 2021). Additionally, CSA approaches are considered important activities for attaining sustainable development goals (SDGs), especially among most rural SSA farmers who are the most vulnerable to extreme weather events and climate change shocks. Most developing countries try to develop cheap but efficient weather forecasting technologies, such as monitoring drones, and bio-sensors to boost agricultural productivity and livestock management and contribute to food security. Precision farming is one of the CSA approaches that have positively influenced the use of minimum water and fertilizer, therefore saving farming costs and improving profits among farmers, as evidenced in Kenya (Maindi *et al.,* 2020).

Environmental conservationists fear that the weak participation of its experts in the global management and knowledge dissemination of CSA technologies could most likely jeopardize the realization of the intended CSA goals. There is a variation in how CSA phenomena are packaged, perceived, and discussed by the concerned actors across the globe and at different levels (IPCC, 2007). Moreover, the relationship between farming activities (crop production and livestock rearing) and climate change is inadequately understood, especially the dual aspect of the sector. The magnitude of the dual effect was well internalized and understood through scientific evaluation of the Intergovernmental Panel on climate change (IPCC) since it was observed that agricultural technologies and systems are great contributors to climate change and its variabilities while at the same time suffering from the effects of climate change shocks. Therefore, scholars argue that upscaling multidisciplinary participatory community-driven approaches would help achieve much as it ties all the multilevel actors such as technocrats, policymakers, extension service providers, and the farmers who suffer the most from the climate change effects (Chandra *et al.,* 2018).

As CSA technology continues to be adopted in the SSA, new emerging trends and enhanced scientific knowledge are developed to make the adoption rate for CSA technologies as successful and effective as possible. Some of the identified emerging issues include agricultural transformation, crop modelling, and the production of hardy crops like pearl millet, cassava, yams, and sorghum, among other technologies (Chandra *et al.,* 2018). Out of the 54 African countries, 48 share the mainland and 6 islands, with only 14 of these sovereign countries representing an average of 26% having developed CSA country profiles. These are countries according to World Bank (2018) are; Benin, Côte d'Ivoire, Ethiopia, Kenya, Lesotho, Malawi, Mozambique, Rwanda, Senegal, Tanzania, Gambia, Uganda, Zambia, and Zimbabwe. Despite the slow and inefficient adoption of CSA technologies in African countries, a few indicators reveal that the use of CSA practices is highly important.

For instance, Lesotho's current farming production systems pay attention to extensive animal grazing systems and extension of crop fields characterized by the mono-cropping system for maize as a dominant crop. However, the aforementioned system is unsustainable. The Lesotho CSA investment plan (CSAIP) provided two alternative CSA pathways for enhancing the adoption of CSA by focussing on commercialization and resilient fields. As a result, CSA attained higher agricultural productivity and incomes, contributed to food security, and provided dietary diversity. The impact of climate change and its vulnerability was also minimized while employment opportunities and commercialization of agriculture were achieved, especially among rural farming households (World Bank, 2018).

Mali participated in a multi-country effort coordinated by the World Bank to create a national Climate-Smart Agriculture Investment Plan (CSAIP). Mali's CSAIP employs an established framework to build strategies and formulate policies on local, national, regional, and international institutions. The country has 12 investments and strategies to boost crop resilience and increase agricultural yields for over 1.8 million farming households by assisting them in adapting to climate change shocks and their variabilities (World Bank, 2018). In East Africa, Kenya developed the Kenya Climate Smart Agriculture Program to run between 2015 and 2030 to enhance agricultural productivity, adaptation, resilience, and mitigation of climate change effects across all production systems. An average of 74% of the Kenyan population lives in rural areas, where 11 million people actively participate in agriculture as a primary economic activity (CIAT, 2015). The agricultural sector in Kenya is classified based on the land size the farmers own. For instance, 0.3-3.0 ha of land size owned by farmers is categorized as "very small landholdings", 3-49 ha is medium-scale production, >50 ha of crops, or > 30,000 ha for livestock is large-scale production (CCAFS, 2017).

Most farmers in Kenya still use traditional farming practices, while approximately 24% of the population is undernourished. Moreover, agriculture contributes an average of 28% of the country's gross domestic product (GDP), where 80% of the total farm yields are at the small-scale (<3 ha) level of land holding (Townsend, 2015). Due to the highlighted issues, Kenya had to formulate the Kenya Climate Smart Agriculture Program (2015-2030) to enable easier coordination between domestic and international CSA approaches to solving the nation's socio-economic challenges. Generally, long-term CSA strategic policies are inadequate in many SSA countries; nonetheless, Kenya has an adequately designed blueprint that enables a more straightforward incorporation of CSA technologies into the current agricultural practices (Barasa *et al.,* 2021). Therefore, the benefits of the CSA sampled approaches prove that the approaches are necessary to enable farming activities to reach sustainable levels and improve the living conditions of smallholder farming communities, especially in the rural setting.

Among the various approaches to Climate Smart Agriculture (CSA), precision farming has emerged as a prominent method, leveraging advanced technologies such as satellites, Global Positioning Systems (GPS), and Geographic Information Systems (GIS). These technologies are crucial in the development of precision agriculture, allowing for detailed monitoring of farmland and real-time mapping of crop yields. This enhanced data collection improves farmers' decision-making processes by providing them with accurate information under shifting economic and environmental conditions (Adesipo *et al*., 2020). In recent years, the use of drones in agriculture has also increased, offering another layer of technological support for managing farming activities sustainably. Despite the potential benefits, drone technology has primarily been adopted by large-scale farmers who possess the financial resources to invest in such innovations.

Conservation agriculture, agroforestry, efficient water use and conservation, and the selection of crop varieties and breeds suited to diverse climatic stresses are all critical components of CSA. Additionally, implementing safety nets, risk insurance, and providing timely climate information to farmers are essential to building resilience (FAO, 2018; FAO, 2019). These strategies have been successfully implemented in various countries across Africa, Asia, Latin America, and the Pacific, demonstrating their global applicability (Branca *et al*., 2011, 2013). Research indicates that practices such as using cover crops, crop rotation, intercropping with legumes, rainwater harvesting, irrigation, integrated nutrient management, contour farming, and terracing require fewer inputs compared to traditional methods. These practices also enhance soil carbon sequestration, where soils capture and store atmospheric carbon, thus contributing to improved soil health and sustainability (Branca *et al*., 2013). By adopting these advanced techniques and technologies, farmers can better manage their resources, increase productivity, and adapt to the challenges posed by climate change.

The adverse effects of climate change on agriculture, income generation, and the welfare of farming communities are addressed through the adoption of strategies that enhance resilience to climate-related challenges. Choosing farming practices that incorporate Climate Smart Agriculture (CSA) principles is crucial for reducing the impact of climate change and addressing food insecurity. CSA practices serve as a framework for assessing how changes in farming methods can effectively respond to the challenges posed by climate variability (FAO, 2019). One notable CSA practice is sustainable land management, which can enhance agricultural productivity, stabilize farming systems, and mitigate climate change effects. CSA emphasizes the importance of tailoring practices to the specific conditions of each region, given the varying impacts of climate variability. Additionally, the effects of climate change are not uniformly experienced across different socio-economic groups. Small-scale farmers, particularly in developing countries, are disproportionately affected due to their reliance on rain-fed agriculture. They face heightened vulnerability to extreme weather events such as droughts, floods, heat waves, and unusual snowfall (Chepkoech *et al.,* 2020). Small-scale farmers growing crops like African indigenous vegetables (AIVs) experience diverse impacts from climate change based on their adaptive capacities, which are influenced by factors such as access to resources, land topography, and land use purposes. There is a growing consensus that while CSA adaptation strategies are crucial, it often takes significant time for the benefits to become evident.

Agroforestry is a CSA adaptation strategy that helps curb climate change variability and food insecurity. For instance, agroforestry practices such as planting leguminous trees during fallow periods can lead to high crop yields in the tropics and create carbon sinks capturing greenhouse gasses (carbon) from the atmosphere (Reppin *et al.,* 2020). However, carbon stocks in agroforestry strategies in the tropics vary due to diversity in the agroforestry practices and where the practice is conducted, implying that the strategy is site-specific. The contribution of agroforestry adoption strategies to the farming communities' livelihoods is determined by their biophysical and socio-economic conditions (Dumont *et al.,* 2019). Moreover, oftentimes, households rely on indegineous knowledge and advice from friends to adapt to climate change variability and severe weather conditions. Mostly, they are inadequately informed on the nature of the emerging climate change events, their associated challenges, and the required strategies to adapt effectively. Some farmers might have complete information concerning climate change-specific mitigation strategies. However, lacking resources might make their responses ineffective (Ogada *et al.,* 2020).

Effective climate change adaptation strategies require a comprehensive approach encompassing policy makers, extension service providers, researchers, communities, and other state and non-state actors. Agroforestry is a way of diversifying agroecosystems using integrated approaches combining tree planting alongside crops and livestock hence building resilience against climate change shocks. This CSA practice can boost food production in an area, reduce the consequences of climate variability, and enhance resilience that results in improved food security. Trees occupy approximately 10% of the world’s farmlands; therefore, the potential for agroforestry should not be underestimated. Trees serve as wind shields and shelter belts, protecting crops from extreme wind storms. Fodder species such as *Vitellaria* *paradox* and *Faidherbia albida* are used to cover the soils against erosion and act as wind brakes as well. Moreover, their leaves are harvested and fed to livestock during drought seasons (Martin *et al.,* 2016).

In mountainous regions, climate change adaptation strategies pose a challenge and therefore require a holistic approach targeting non-climatic factors such as terracing as an adaptive response to steep gradients (Capitani *et al.,* 2019). In mountainous ecosystems of East African regions such as Ethiopia and Kenya, climatic change and variabilities are characterized by rising temperatures, erratic precipitations, and prolonged aridity. Temperature shifts in these mountainous regions could benefit farmers through a change in agricultural activities, with farmers adopting maize and beans farming which is a positive effect of climate change (Adhikari *et al.,* 2015). However, with higher temperature increases in these elevated areas, there is a likelihood of rising pests and diseases with the potential to damage crops. Pest infestation has contributed to increased prices of pesticides for pest control. Weed infestation is also catalyzed by climate change which favors the growth of weeds in wheat crops, thereby lowering wheat yields (Malhi *et al.,* 2021). In these mountainous regions, conservation agriculture is likely to preserve soil cover, protecting it from soil erosion and conserving soil water and nutritional contents. In South Asia, for instance, farmers are adopting no-till practices (zero tillage) for wheat cultivation, lowering cultivation costs by 15 percent and increasing yields (Erenstein *et al.,* 2012).

CSA research and technology has developed and disseminated additional new techniques and tools and formulated agricultural policies that open a new dimension for the agricultural sector to adapt and mitigate climate change-related risks (Partey *et al.,* 2018). Some of the highlighted technologies and approaches developed to cushion farmers against climate change-related shocks include; solar-powered drip irrigation technology, the use of highly productive and drought-resistant hybrid seeds for various agricultural commodities, integrated tree-crop-animal husbandry systems, agricultural insurance for both crops and livestock, climate-smart agricultural information systems, formulation of national and regional climate change action blueprints and policies. However, climate change adaptation practices are still under research as there is still room for more innovations on CSA concerning the prevailing circumstances affecting their adaptability; for instance, complexities of an area's socioeconomic, political, cultural, and environmental conditions. The factors above may get farming households to implement CSA practices or not, depending on their expected utility as viewed by the farmer (Zougmore *et al*., 2016).

Policymakers and other stakeholders strive to assist small-scale poor farming households adjust to climate change shocks and their vulnerabilities to achieve food security targets as revealed in the sustainable development goals (SDGs). Transferring knowledge and skills to CSA practices would ensure that farmers in the country benefit through the initiative. Since its introduction by the Food and Agriculture Organization (FAO), conservation agriculture (CA) as one of the CSA practices has been widely accepted as a key farming innovation delivering on several pillars of the CSA. A study by Buah *et al.* (2017) noted that CA has been built on the indigenous slash-and-burn farming approach contributing to; zero/minimum tillage; protection of soil through mulching; and crop rotation which reduces soil degradation. Empirical observation reveals CA to have a positive effect on agricultural productivity. For instance, areas practicing CSA have had an increased yield of food crops like corn, sorghum, and millet, especially in degraded soils, thus providing economic importance and benefits from the crop rotation system of farming. According to Bayala *et al.* (2012), meta-analyses in the arid and semi-arid areas of many countries of the SSA attributed CA to improved land fertility, curbing soil erosion, enhancing soil water/moisture retention capacity, improving soil nitrogen availability, and increasing grain yield of cereals (Kermah *et al.*, 2017).

Climate change-related risks such as unpredictable precipitation patterns, unending drought, increased run-off, and rising temperature are curbed by CA, which protects soil cover through minimum tillage. Moreover, minimum tillage will help maintain soil structure, which has multiple benefits to farmers (Kermah *et al.,* 2017). This includes lower run-offs, high water infiltration, enhanced soil organic matter, and high soil water retention. Planting of legumes such as cowpea (*Vigna unguiculata*) and normal bean (*Phaseolus vulgaris*) used in CA helps to fix nitrogen (N) in the soil hence increasing soil nitrogen availability translating to higher grain yields. Promoting minimum tillage farming practices in CA reduces operational costs (labour costs) in land preparation while saving time; hence farmers can synchronize their planning with the onset of rains. The use of crop diversification and rotational intercropping techniques in CA significantly mitigate the risks associated with crop failure, acting as safety nets for household farmers when one crop fails to yield results as anticipated (Buah *et al*., 2017). However, to enable small-scale farmers to adapt to and mitigate climate change, quantification of net fluxes of greenhouse gases (GHGs) and carbon sequestration in CA is viewed as an information gap. The key principles underpinning CA are overlooked in the measurement of GHGs. Normally, organic residue use and minimum soil disturbance have been promoted as options for reducing GHGs, such as carbon emissions on farmlands. For instance, applying nitrogenous fertilizer and manure in the planting fields increased crop biomass production, reducing carbon loss on the farm (Soler *et al.,* 2011).

Using planting pits as water harvesting techniques to conserve water in the production of drought-tolerated crops helps retain the water for the production of the highlighted crops, especially in the West African countries Mali and (Wouterse, 2017). The planting pits technique was developed from traditional knowledge and has been incorporated as one of the best practices in the CSA to be promoted in the arid and semi-arid regions of the world. This system involves digging up pits at 20-30 cm diameter and 10-15 cm depth to accumulate water before planting with or without using organic manure, such as plant residue or compost, and animal manure (Partey *et al.,* 2018). Farmers use these practices mostly on dry valleys, bush fields normal and degraded lands to maintain soil moisture, curb soil erosion from the farmlands, and enhance soil fertility. Despite laborious practices, the practice is still widely used among farmers in the West African region, especially in the dry seasons and high temperatures. Drought-tolerant crops such as sorghum, millet, cassava, and normal leguminous crops like cowpeas are successfully produced using the highlighted technique by employing other CA techniques such as the application of animal manure or compost (Schuler *et al*., 2016).

Rainfall is vital for farming; however, too much rain results in floods and soil erosion on farmlands, destroying crops and degrading top soils. The use of adaptation and mitigation measures such as stone bunds and contour ridges to reduce soil erosion and collect excess run-off water for farming processes have been increasingly embraced among smallholder farmers. Using stone bunds as erosion barriers is a useful way of enhancing the increase in crop yields by 59% (Zougmore *et al*., 2014). Stone bunds involve pilling stones and boulders at close range along the natural contours of the fields or farmlands to reduce the speed of run-off water, ultimately taming erosion and improving water infiltration. Due to its ability to lower the effects of floods and extreme droughts on farmlands, stone bunds, as a CSA technique, remarkably improve the adaptation of farming systems to climate change. Moreover, the stone band is considered a precision agricultural technique as it concentrates water for easier absorption by plants (Aune *et al.,* 2017). Contour ridges are similar to stone bunds used by farming households to tackle erosion menace and improve soil water utilization efficiency for farming (crop production). Contour ridges are CSA practices, also called micro-catchment systems, used to harvest rainwater during the rainy seasons to be used in extreme cases of prolonged drought. These techniques are primarily practiced in the arid and semi-arid regions of West Africa. Unlike stone bunds, they are earthen structures raised between 15-20cm above the soil surface, and the distance between ridges is adjusted between 0.5-10m depending on rainfall characteristics of the farmland area/region. Integrated soil fertility management techniques like compost, organic manure, and fertilizers may be combined with contour ridging for enhanced agricultural yields (Partey *et al.,* 2018).

Rain-fed agriculture increases farmers' vulnerability to climate change effects and its variabilities. Irrigation potential is immense; however, areas with irrigation facilities are relatively few. Strategies for enhancing water availability on agricultural fields have been underway, with calls for adopting drip irrigation techniques as CSA practice, especially for farming high-value vegetables (Wanvoeke *et al.,* 2016). Solar-powered drip irrigation technology is on a high adoption across Kenya due to its ability to efficiently utilize water at a lower cost. Evidence from the literature reveals that agricultural areas fitted with drip irrigation facilities could double their yields under normal conditions of the field than the control fields. However, the initial investment costs for setting up drip irrigation facilities are relatively high to be afforded by most small-scale farmers, affecting its adoption. There is a need for support from government and other development experts such as NGOs, to kick-start the technology by providing infrastructure and the initial investment costs (Partey *et al.,* 2018).

### 2.8.1 Climate smart agriculture developments in Kenya

The government of Kenya has embraced and recognized CSA as a major tool to deal with challenges caused by climate change. The country has put effort into scaling up CSA through various programs to enhance smallholder farmers' implementation of adaptation techniques. These projects are aimed at enhancing the adaptive capacity of smallholder farmers to climate change risks with and aim of increasing agricultural productivity under changing climate (Endo, 2020). This is achieved through strengthening research in climate change and CSA, scaling up CSA practices, supporting dissemination and improving access to agrometeorological information, promote climate advisory services and market intelligence. Agricultural projects provide farmers with important information that is essential in ensuring efficient production and marketing of their products by embracing innovation and technology (Leahy & Alinyo, 2018). For instance in most African countries agricultural projects are major sources of funding for agricultural activities hence reducing poverty and improving livelihoods of smallholder farmers.

Agriculture is a major sector contributing to the economic growth of most African countries Kenya included. In SSA smallholder farmers produce the majority of the nation's food crops, however, their yields remain low due to among other things the effects of climate change and variability (Amwata, 2020). Kenya has therefore partnered with other stakeholders to design different programs and strategies aimed at cushioning the farmers against the adverse effects of climate change. Some of the projects initiated through the Government of Kenya include The Kenya Climate-Smart Agriculture Project (KCSAP) which is a World Bank-supported project under the Ministry of Agriculture, Livestock, Fisheries, and Irrigation and has had a large impact on smallholder farmers (Okumu, 2021). The project focuses on expanding the use of CSA practices, advancing research and seed systems related to CSA, and improving access to agro-weather information, market opportunities, climate services, and advisory support. Its primary objective is to achieve three key outcomes: increasing agricultural productivity in a sustainable way, enhancing resilience to climate risks, and reducing or eliminating greenhouse gas emissions (Muhumuza, 2019).

The Kenya Cereals Enhancement Programme-Climate Resilient Agricultural Livelihoods (KCEP-CRAL) is a project designed to enhance capacity building among smallholder farmers for Climate-Resilient cereal productivity which contributes towards national food security (IFAD, 2017). Transformation of Climate action through the utilization of a hybridized Clean and Sustainable Energy as a driver to climate smart agriculture and agribusiness value chain equally is a project funded by Italian Agency for Development Cooperation and the United Nations Environment Programme (UNEP). The project is aimed at promoting climate-smart agriculture resilience among farmers. The project promotes clean and renewable energy in a bid to reduce C02 emissions hence counter climate change and enhance sustainable development which will foster economic development (Ciaccia, 2022). Moreover, the Climate Smart Agriculture program through Climate Resilient Agribusiness for Tomorrow (CRAFT) supported by SNV aims to boost agricultural productivity and smallholder incomes, enhance resilience to climate change, and lower greenhouse gas emissions.

In 2014, the Finance Innovation for Climate Change Fund (FICCF) commissioned a scoping study to document the current Climate Smart Agriculture (CSA) initiatives in Kenya's non-ASAL areas (FICCF, 2014). The primary goal of the FICCF CSA initiative was to support smallholder agriculture that is low in carbon, resilient to climate change, efficient, productive, and sustainable, while also facilitating the scaling up and expansion of promising CSA investments. The study examined connections, weaknesses, and failures within various value chains. It highlighted that improving the reliability of weather forecasts was crucial for enhancing the capacity all stakeholders to anticipate weather conditions. Accurate forecasts are vital for farmers to select appropriate crop varieties, adapt their farming practices, and implement other important measures to optimize their benefits (Rao *et al.*, 2005). The study also recommended a collaborative approach involving farmers, the Kenya Meteorological Department (KMD), and extension service providers to forecast, package, and disseminate agro-weather information, which could significantly reduce uncertainties (FICCF, 2014).

## 2.9 Agrometeorological information and the adoption of CSA practices among smallholder farmers

Agriculture is a fundamental sector for many economies, especially in sub-Saharan Africa (SSA), where it is essential for food security and rural employment (Mumo *et al*., 2018). This region, with a current population of approximately 950 million people about 13% of the global total is projected to grow to around 2.1 billion by 2050 (Siamabele, 2021). This demographic expansion is driving a rising demand for food, underscoring the critical role of agriculture in maintaining food security (Rahaman *et al*., 2021). In SSA, agriculture significantly impacts the economy, both directly and indirectly. On average, the sector contributes approximately 15% to the region's gross domestic product (GDP), with variations ranging from as low as 1.9% in Botswana to as high as 57.4% in Sierra Leone (Fikre *et al*., 2020). Agriculture also employs over half of the labor force in SSA. For many rural residents, agriculture is the primary livelihood source, with small-scale farms constituting about 80% of all farms in the region and providing employment to around 175 million people (Kinkela *et al*., 2018; Siamabele, 2021). In Kenya, agriculture plays a central economic role, contributing roughly 33% of the GDP. It is a major employment sector, accounting for 60% of jobs, and is crucial for exports, making up 65% of the country's total export value (Group, 2018).

Climate variability and change have significantly impacted the agricultural sector, with projections indicating that these effects will intensify throughout the 21st century (Kogo et al., 2021). The Intergovernmental Panel on Climate Change (IPCC) reports that many countries are expected to experience considerable climate changes, including rising average temperatures, increased frequency of heatwaves, heightened stress on water resources, desertification, elevated $CO_2$ levels, and more frequent heavy precipitation events (Ochieng *et al*., 2016). These changes threaten food security by reducing agricultural production due to lower rainfall, decreased soil moisture, and higher temperatures. Small-scale farmers are particularly vulnerable, which undermines global progress in reducing poverty, improving food security, and promoting sustainable development. Approximately 475 million smallholder farmers worldwide, who typically manage less than 2 hectares of land, are food insecure and live under challenging conditions (Lowder *et al*., 2016).

The impact of climate change is especially pronounced in sub-Saharan Africa (SSA), where agriculture is a primary livelihood for many rural communities. The sector's reliance on rainfall makes it highly susceptible to the effects of climate change. SSA has experienced warmer temperatures over the past century, and this trend is expected to continue due to greenhouse gas emissions (Bogale & Temesgen, 2021). Rainfall patterns are becoming increasingly erratic, underscoring the need for adaptation strategies to manage climate variability and change effectively. These strategies are vital for enhancing resilience, protecting farmers' livelihoods, and ensuring food security. In Kenya, where agriculture is predominantly rain-fed, the impacts of climate change are particularly severe. The frequency and intensity of extreme weather events, such as droughts and floods, are likely to increase. Changes in rainfall patterns and temperature regimes can disrupt local water balances and affect the timing and viability of agricultural production (Tadesse & Dereje, 2018).

The impacts of climate change on agricultural productivity have driven the need for resilience-building among farming households. Consequently, agricultural policies are increasingly designed to address climate change-related challenges (Abegunde *et al*., 2020). In Kenya, the government, through various ministries, has developed strategies aimed at helping farmers particularly small-scale producers adopt resilient and sustainable farming practices that enhance productivity and food security. One major contributor to climate change is the accumulation of greenhouse gases (GHGs) due to human activities such as deforestation, industrialization, and the burning of vegetation (Vermeulen, 2014). Agrometeorological services play a critical role in supporting farmers' decision-making processes and enhancing their ability to adapt to climate change. Reliable and precise agrometeorological information is essential for guiding farm operations, especially in the face of climate variability, which poses significant risks to agriculture (Agarwal *et al*., 2021). Agrometeorological information can be obtained through both conventional methods and indigenous knowledge. Conventional methods involve gathering data from weather stations and using predictive modeling developed by researchers (Vaughan *et al*., 2019). In contrast, indigenous knowledge includes insights passed down through generations within local communities. This traditional knowledge encompasses the observation of plant and animal conditions and various environmental indicators, such as bird calls and other animal sounds (Mumo *et al*., 2018; Partey *et al*., 2018). By integrating this indigenous knowledge, farmers can anticipate climate-related disruptions and develop strategies to mitigate production losses.

The application of climate services, particularly agrometeorological services, represents a notable advancement in supporting farmers' decision-making and enhancing their adaptive capacities (Tarchiani *et al*., 2021). In Kenya, the integration of agrometeorological information into farming practices has proven beneficial. Evidence suggests that consistent access to such information helps farmers manage risks associated with increased climate variability and change. For smallholder farmers dependent on rain-fed systems, this information can significantly improve climate resilience and coping strategies (Bacci *et al*., 2020). Seasonal climate forecasts are particularly valuable as they provide timely, relevant information that extends the planning horizon for farmers. This increased lead time has fostered greater interest in leveraging these forecasts to improve agricultural outcomes. Farmers and local stakeholders generally appreciate these services for their role in enhancing agricultural production. Research by Tarchiani *et al*. (2018) highlighted that agrometeorological information services could lead to increased crop productivity, reduced input costs, and less labor time. For example, in Mauritania during the 2015 and 2016 growing seasons, the use of these services resulted in a 64% increase in sorghum yields. This improvement was attributed to the selection of suitable crop varieties and optimal sowing dates, which mitigated the effects of an early end to the rains and prevented pest infestations at season's end. Furthermore, farmers experienced cost savings due to fewer losses related to opportunity costs and a reduced need for additional weeding, particularly for those who planted in off-seasons (Tarchiani *et al*., 2021).

Adaptation strategies to manage climate variability and change are vital for enhancing resilience, protecting farmers' livelihoods, and ensuring food security. These strategies are especially valuable for resource-constrained farmers (Tarchiani *et al*., 2021). In Western Kenya, the effects of climate variability and change on agriculture are pronounced, given the region's reliance on rain-fed farming. Farmers in this area have implemented various adaptation measures to cope with these challenges, including diversifying crops, adjusting planting schedules, growing drought-resistant and early-maturing varieties, using high-yielding crops, and practicing agroforestry (Mumo *et al*., 2018). However, the effectiveness of these strategies is often limited by challenges such as inadequate access to climate adaptation information, insufficient institutional support, and unclear public policies on adaptation (Onyango *et al*., 2021). To address these obstacles and improve the success of adaptation efforts, it is crucial for farmers to have access to accurate and detailed information about future climate conditions. Comprehensive agrometeorological data plays a key role in enhancing agricultural systems and supporting effective adaptation strategies in all regions (Zhang *et al*., 2016).

Numerous studies have examined the impact of climate variability, agrometeorological information, and various socioeconomic and institutional factors on agricultural productivity, often focusing on these elements separately (Chadalavada *et al*., 2021; Ochieng *et al.,* 2016; Tarchiani *et al*., 2021). Research in Ethiopia has shown that farmers' adaptation decisions in watershed areas are influenced by a range of factors, including household size, the gender of the household head, the size of the cultivated land, educational attainment, the availability of climate information and extension advice, and the number of land parcels managed (Asrat & Simane, 2018). The study by Ochieng *et al*. (2016) highlights that climate variability and change have a significant impact on agricultural production, but these effects vary across different crops. For example, while low temperatures negatively affect maize yields, they can have a beneficial impact on tea cultivation. Similarly, Tarchiani *et al*. (2018) found that rural farmers utilize weather and climate services to make both strategic and tactical decisions, which help manage production costs and enhance income through improved efficiency.

Various strategies have been proposed to mitigate the impacts of climate change on agriculture. Among these, Climate Smart Agriculture (CSA) practices stand out as particularly promising. CSA aims to enhance agricultural productivity, build resilient and sustainable food systems, and reduce greenhouse gas emissions. Researchers advocate for policymakers to consider the factors influencing the adoption of CSA practices to develop informed, practical, and achievable strategies that support the successful implementation of these practices among farmers. Farmers stand to gain considerable benefits from adopting a range of CSA practices, as these strategies can act both as substitutes and complements, creating synergies that improve overall outcomes. Thus, it is recommended that farmers employ a combination of CSA practices to build resilience against climate change impacts and address various factors affecting agricultural production (Abegunde *et al*., 2020). Integrating multiple CSA practices can enhance the effectiveness of adaptation efforts, leading to better productivity and sustainability in the face of climate-related challenges.

CSA practices including adopting improved land and efficient water use strategies could assist smallholder farmers, especially in SSA, in achieving agricultural development and food security and adapting and mitigating climate change shocks (Mango *et al.,* 2018). Technologies such as improved water management through irrigation strategy adoption among small-scale farmers and conserving soil moisture through planting of cover crops and control soil erosion are more suited to the majority of farmers in the SSA. However, the available data reveals that the total land under cultivation in Africa concerning the whole cultivated land is approximately 6 percent, more than 14 percent for Latin America and 37 percent in Asia (Khan

& Hanjra, 2008). Using manure, soil water conservation, agroforestry, intercropping, and incorporation of livestock rearing in farming activities enhance food security and cushion farmers against extreme climate change shocks (Kiboi *et al.,* 2019). When implemented as a whole, CSA practices can increase agricultural productivity, reduce and remove toxic gasses from the atmosphere, and enhance national food security. Moreover, incorporating extreme weather-adaptable crops like cassava, millet, and sorghum enhances food security in the wake of climate change challenges (Victory *et al.,* 2022). Despite the rising debate about the sustainability of agricultural activities and food security in developing countries, small-scale farmers still find it challenging to incorporate CSA most efficiently. Additionally, most rural farmers have inadequate knowledge of implementing these practices.

In Kenya, farming practice is classified into small-scale and large-scale, small-scale producers mainly practice in rural areas where agriculture is viewed as a significant economic activity in the fight against unemployment and poverty. Ideally, these small-scale farmers are resource-constrained, so agricultural productivity remains low (Kamwamba-Mtethiwa *et al.,* 2016). Adopting irrigation among small-scale farmers in Kenya aims to align with national development goals such as improving farm productivity, achieving food security, and contributing to economic growth. Irrigation as a CSA practice includes using either human-powered or animal-powered water pumps, solar pumps, electric pumps, and fuel engine-controlled pumps. The majority of the rural farmers in SSA still use indigenous methods in their farms, such as watering using buckets, watering cans, or blocking streams implying that the total area of farmland irrigated is insufficient as the traditional employed irrigation method is ineffective and laborious. Using irrigation among small-scale farmers in SSA is still viable since the continent has abundant freshwater sources from lakes, rivers, natural streams, and springs (You *et al.,* 2011). However, the distribution of these new water resources is uneven across agro-ecological regions.

Agricultural adoption has gotten much attention because of its contribution to increased productivity and incomes, particularly in developing countries, where agriculture is critical for eradicating poverty, malnutrition, and hunger and sustaining humble livelihoods (Branca *et al.,* 2011, 2013; McCarthy *et al.,* 2011). As a result, a plethora of agricultural technologies, as well as an enormous amount of literature, has been created. Despite these efforts, farm-level adoption of new technology remains a complicated problem. This conclusion is supported by numerous studies conducted in Africa and Asia (Mango *et al.,* 2017; Moysiadis *et al.,* 2021; Regan, 2019). Farmers have been observed to adopt CSA practices differently depending on their varying demographic and socio-economic needs. Moreover, introducing smallholder farmers' empowerment and capacity building about CSA practices has positively impacted their farming activities. For example, it was found that training farmers on CSA practices in Kenya enhanced the adoption of these practices (Zakaria *et al.*, 2020). However, most projects require high implementation costs and other hindrances that limit their adoption among small-scale farmers. Therefore, promoting new CSA technologies through farmer training gives them a wider choice of alternatives based on farmer-specific needs and affordability. Moreover, it creates a knowledge base called human capital that enables further dissemination of these new practices among other untrained farmers.

Adopting CSA practices is viewed as a process where small-scale farmers utilize environmentally friendly agricultural practices as the best product choice. Adoption is a process that follows five sequential stages: awareness, interest, evaluation, trial, and finally, adoption of the preferred activity by the farmer (Victory *et al.*, 2022). Even though it does not practically follow the highlighted order sequentially; for instance, interest may precede awareness. Moreover, adopting CSA practices among sorghum farmers increases climate adaptation skills, improves agricultural productivity, conserves the environment, and enhances food security. Without smallholder farmers adopting climate-smart agricultural practices, they will become increasingly vulnerable, and agricultural production will suffer significantly (Nyang'au *et al.*, 2021). Adopting CSA practices helps reduce climate change's negative consequences and capitalizes on its benefits. According to previous studies, farmers' most commonly used adaptation practices include irrigation, improved crop varieties, crop diversification, field diversification, shifting planting dates, and income-generating activities (Destaw & Fenta, 2021).

Smallholder farmers are particularly vulnerable to the impacts of climate change due to their limited capacity to adapt effectively. Research shows that only a small fraction of these farmers utilize available adaptation options (Fosu-Mensah *et al*., 2012). In Kenya, various initiatives have been introduced to promote Climate Smart Agriculture (CSA) practices. However, despite these efforts, the uptake of sustainable and productivity-enhancing technologies remains relatively low among smallholder farmers (Murray *et al*., 2016). The low adoption rates are often influenced by local conditions and specific agro-ecological zones. For instance, a study by Mutsotso *et al*. (2011) in Embu and Taita found that the adoption of biodiversity conservation technologies was limited by a lack of available technologies in local agro-veterinary shops. Similarly, Murray *et al*. (2016) identified that the acceptance of new technologies among smallholders in Kenya’s central highlands was significantly influenced by their resource endowments. Additionally, Ogada *et al*. (2014) reported that low adoption of fertilizers and improved maize varieties in Kiambu, Embu, and the Coastal lowlands was due to factors such as unfavorable climatic conditions, high input and labor costs, limited access to extension services, scarcity of inputs in local shops, and gender-related issues, as well as low financial resources.

### 2.10 Socio-economic, institutional factors and adoption of CSA practices

Empirically, smallholder farmers' adoption of CSA practices is highly shaped by socio-economic, institutional, farming location characteristics, level of informational awareness, and level of technological development of an area, including the availability and access to essential infrastructural services, social capital, and climatic factors. For instance, households vary in the choice of farming systems adopted, the size of the farming plot owned, and their origin (cultural values). Moreover, resource constraints influence the kind of technology to be adopted by farmers within an area (Negera *et al.,* 2022). The adoption of CSA practices is empirically and econometrically correlated (Oyetunde-Usman *et al.,* 2021). The technological complementarity or substitutability of CSA practices could explain the highlighted correlation. The presence of such relationships in the adoption of CSA practices encourages the use of the Multivariate Probit (MVP) model in the econometric estimation of these practices. In reality (empirically), agricultural activities, especially among small-scale farmers in the SSA region, are dictated by multiple idiosyncratic and related risks that influence farming households to adopt multiple CSA practices to cushion them against climate change risks. However, a typical farmer makes rational decisions through the combined CSA practices assumed dependent on his attributes. In this regard, the adoption of CSA practices is promoted in packages such as the use of fertilizer, manure, improved seeds, irrigation, and use of pesticides or/and herbicides due to their complementary role.

In places where farming households are exposed to several climate change shocks; producers adopt multiple CSA practices that may improve their farming productivity. However, the aforementioned adoption style may be bound to conflict of strategies proposed for adoption among the household members based on their perceived utility, possibly explained by the heterogeneous distribution of household choices observed across the SSA (Teklewold *et al.,* 2013). The rationale for adopting multiple CSA practices has changed from using one-strategy-fits-all to enhancing productivity among small-scale farmers to promoting a hybrid system accounting for improved societal welfare and environmental conservation.

Since its inception in 2010, climate-smart agriculture has elicited global debate on its ability to contribute towards addressing sustainable development constraints in agriculture.

This led to several initiatives to educate stakeholders in promoting the CSA phenomenon. For instance, a global alliance for climate-smart agriculture (GACSA) launched in 2014 at the United Nations Secretary General's climate summit was aimed at pushing the adoption of multiple CSA practices with a target of reaching over 500 million small-scale farmers (Rosenstock *et al.*, 2015). Worldwide the promotion of adoption of CSA practices has been on the rise with regional efforts being made. For example, New Partnership for Africa's Development (NEPAD), implements diverse projects to increase CSA adoption by farming households the aim is to increase adoption rates from 6 million to 25 million households worldwide. Individual countries have also made substantial efforts to contribute to enhancing resilience against the effects of climate variability by promoting the adoption of CSA practices. Examples of success cases in CSA adoption include countries such as Peru, Tanzania, and China with Tanzania recording a triumphant story of agroforestry, while China embraced sustainable grazing as an efficient CSA practice (FAO, 2019).

It is of essence to note that CSA is not an entirely new set of technology to be adopted by farmers but rather an integrated technology that enhances agricultural productivity and environmental conservation. Governments, through their policymakers, development partners, and NGOs, work at various levels to implement CSA activities (Rosenstock *et al*., 2015) with the Green Climate Fund (GFC) identifying CSA as a significant area to prioritize for investment in Africa and Asia. Moreover, the Global Environmental Facility (GEF) sets its main goal on effectively implementing CSA and enhancing food security in Africa. However, CSA implementation is still inefficient and ineffective, sparked by conflicting interests between CSA implementing experts and the policymakers, mostly politicians aiming to implement political agenda at the detriment of mitigation measures. This can be addressed by supporting the implementation of agricultural policies and strategies that seek to attain a nation's food security, improve households' social welfare, and build resilience in under prevailing climatical changes and its vulnerabilities. To achieve CSA-related goals, all the development partners align their agenda to three principles to understand, identify, and select the most efficient CSA practice (Matteoli *et al*., 2020). The three principles include the following;

CSA technologies address risk: To effectively enhance food security, agricultural practices must address risks associated with weather, climate change, and variability. These risks encompass extreme weather events such as flooding, drought, rising temperatures, decreased precipitation, and delays in the onset of rains. Climate Smart Agriculture (CSA) practices should be designed to mitigate these risks both in the short term and long term.

In the short term, CSA practices aim to boost productivity per unit of land (hectare) within a given growing season. This involves optimizing immediate agricultural outputs despite challenging climatic conditions. In the long term, the goal is to stabilize production and reduce yield variability over time as climate conditions evolve. By implementing CSA practices, farmers can enhance their resilience to climate-related disruptions, ensuring more consistent and reliable agricultural productivity and ultimately improving food security.

CSA technologies have multiple benefits: The practices must contribute to the achievement of at least productivity, resilience, and mitigation. Productivity is the main agenda in developing countries such as Kenya, which rely on agriculture as one of the significant contributors to the GDP. Therefore, CSA practices should contribute towards improving productivity by reducing the effects of climate variability and change on both crops and livestock. Effective CSA practices should have the capability to enhance farmer preparedness and resilience towards extreme weather events by harnessing synergies and reducing risks.

CSA technologies are issue-specific in space and time: CSA practices are applied differently in terms of the social and cultural alignment of the household where they are practiced. Since the biophysical and social status of farming environments and families change over time, whether a practice is CSA or not changes. A CSA practice adopted in a place today may not necessarily be a CSA practice in the same region over some time.

The effectiveness of any CSA practice implemented may be influenced by the location in which the practice is implemented. This means that the ability of a CSA practice to mediate the effects of climate change may be region specific characteristics. Therefore, it is important to consider region specificity when implementing CSA practices at the farm level is a critical component for mediating against effects of climate change and contributing towards development in agriculture (Rosenstock *et al*., 2015). A few studies have been conducted for systematic analysis of the effects of CSA practices (Branca *et al*., 2011; Ogle *et al*., 2014); however, CSA practices are mainly explained and supported with case studies having inadequate information to attribute the effects to CSA practices conclusively. Insufficient information on CSA practices and lack of uniform understanding of the CSA impacts. The lack of reliable evidence base for the CSA impact contributes to the controversy surrounding CSA, further preventing technocrats and policymakers from efficiently developing effective CSA technologies.

The adoption of agricultural technology is influenced by a range of socioeconomic and institutional factors. Key determinants include the age, gender, education level, asset endowment, farm size, and farming experience of the farmers. Moreover, the decision to adopt new technologies is also affected by factors such as awareness of the technology, its characteristics, the role of implementing organizations, and market conditions (Kong & Castella, 2021). For small-scale farmers, resources and capital endowments such as wages, savings, access to credit, and insurance play a crucial role in technology adoption. These financial resources serve as a "safety net" during difficult times, enabling farmers to explore and invest in innovative practices that contribute to long-term adaptation and sustainability (Sibiko & Qaim, 2020). On the other hand, many technological advancements require substantial capital investment, which has historically been beyond the reach of many rural farmers. Consequently, those with more financial resources are more likely to adopt climate-smart agriculture practices compared to their less-resourced counterparts (Glazebrook *et al.,* 2020). Small-scale farmers profit from the existence and interaction of markets moreover, it has been shown that market imperfections impact the acceptance of novel approaches (Glazebrook *et al.,* 2020; Kong & Castella, 2021). Additionally, studies suggest that technology adoption becomes simpler when implementation tools are readily accessible and affordable in the local marketplace (Ogada *et al.,* 2014).

Institutions also have a huge impact on the implementation of agricultural practices as Kong and Castella (2021) assert that effective implementation of CSA practices requires institutional involvement across all levels. Local collectives and civil society organizations play a pivotal role in this process by contributing to various aspects essential for the successful adoption of CSA practices. These organizations are instrumental in creating assets, providing access to crucial information, mobilizing resources, and fostering capacity and capability development among farmers. They also help establish the necessary linkages for the effective implementation of adaptive strategies. Furthermore, a supportive policy environment is crucial for the successful deployment of CSA practices. Policies that promote reimbursement for environmental services, fund research, and facilitate the dissemination of knowledge and advisory services significantly enhance the effectiveness of CSA initiatives. Such policies create an enabling environment that encourages the adoption of new practices, supports innovation, and ensures that farmers receive the necessary support to implement and benefit from CSA practices. Tomlinson and Rhiney (2018) emphasize the importance of expertise in shaping farmers' decisions and attitudes about adopting new technologies or practices and divide and categorize awareness into three categories: comprehension, how to adapt, and fundamental adoption values. The ability to comprehend the technology's driving implementation principles is known as theory knowledge. "Theory knowledge" necessitates understanding the technology's guiding implementation concepts, while "how-to knowledge" necessitates understanding how the technology is implemented. According to surveys, more knowledgeable and educated farmers continue to be at the forefront of technology adoption (Glazebrook *et al.,* 2020). Despite the critical role of knowledge in decision-making and innovation adoption, research indicates that small-scale farmers often lack access to information (Hermans *et al.,* 2021; Zhang *et al.,* 2020). For example, farmers may be aware of CSA practices but unable to adopt them due to their perceived inefficiency and incompatibility with their needs, desires, values, and attitudes (Tomlinson & Rhiney, 2018).

### 2.10.1 Empirical literature on determinants of adaptation to climate change and variability

Climate change vulnerability portrays different interpretations in various disciplines and has no precise and concise definition. However, the standard definition of vulnerability looks at the extent of damage or injury likely to be occasioned by a system as a result of its exposure to a hazard. As climate change occurs, agricultural producers, their farmlands, and farming systems become predisposed to these climate change disorders determined by exposure, sensitivity to these shocks, and adaptive ability. According to IPCC (2007), vulnerability is the level at which an individual, institution, or system becomes susceptible or unable to cope with climate change shocks and extreme weather conditions. Therefore, vulnerability embodies a system's character, intensity, degree of predisposition to climate change shocks, and sensitivity and adaptability. The adaptive capacity of a system is its ability to lower the likely effects of climate change and its vulnerability by using the available opportunities or employing measures to handle these shocks.

Sensitivity, on the other hand, refers to the extent to which a sector, institution, or farming household is affected by climate change-related shocks, which might be positive or negative (IPCC, 2007). In this study's context, vulnerability is the level at which a sorghum farming household is susceptible and unable to adapt to the effects of climate change stresses. How these sorghum farmers react to climate change and their vulnerabilities varies in the context of socio-economic, institutional, environmental, and topographical factors surrounding them. For instance, the computed socio-demographic vulnerability indices indicated that female-headed farming households were more vulnerable to climate change shocks than their male counterparts (Alhassan *et al.,* 2018). Even though male-headed farming households were more vulnerable based on the dependency index compared to females, a relatively larger proportion of female-headed farming households have more orphans to care for than male-headed farming households, hence more vulnerable. The likely explanation for the highlighted observation is that a higher dependency ratio implies more family members in a farming home depending on the limited resources of the vulnerable household heads or decision-makers, the majority (female-headed farming households in this case). This means that female-headed households use more finance to take care of the needs of family members, leaving little to no resources to adapt to the climate change shocks.

Empirical research reveals that the majority of farming households, mainly from flood-prone areas of developing countries in the SSA like Kenya, react to climate change by adapting to these shocks or migrating to less-prone regions. A large field in economics and other social sciences links climate change related factors to migration. Several types of research focus on the role of the farming sector in influencing the migration of farming households. Most of the shifts are specific to a given geographical setup. For instance, Berlemann and Steinhardt (2017) suggest that climate changes and extreme weather events induce the migration of populations through the shift in amenities and rural-urban migration. However, this activity is observed as a way of avoiding climate change effects rather than a mitigation measure.

The more context-specific factors include but are not limited to; Access to credit facilities that are more likely to promote the adaptability of CSA practices among farming households. Farmers with access to farming finances were revealed to be 18% more likely to practice off-season farming to reduce the effects of climate change (Moranga *et al.,* 2016). Therefore, there is a need to enhance the availability of credit facilities which could promote the adoption of CSA technology to lower the adverse effects of climate change shocks and their vulnerabilities. According to Wekesa *et al.* (2018), adoption of new farming strategies requires funds, and farmers who cannot borrow may be limited in embracing adaptation measures that require heavy investment. Farmers in Kenya have formed groups that facilitate sharing farming ideas amid climate change challenges. This observation brings forward the argument that being a member of a development group increases the likelihood of farming households adopting CSA practices due to the mobilization of resources such as credit facilities and information transfer from one farmer to the other. This is supported by the findings of Gido *et al*. (2015) who observe that belonging to farmer-related groups and organizations facilitates easier access for extension agents to reach members, lowers the cost of service delivery through economies of scale, and strengthens the farmer's social capital with other stakeholders.

Radio ownership as an agricultural dissemination pathway influences farmers' adoption of CSA practices. Radio is a powerful information dissemination pathway specifically functional among farmers for spreading scientific climate and weather forecasts. Small-scale farmers do not efficiently use other conventional sources such as newspapers, the internet, and bulletins, especially in rural areas, due to the high cost of acquiring information from these sources, low literacy levels, and lack of proper infrastructure. According to Muema (2018) smallholder farmers, especially in Kenya, rely heavily on radio as the primary cheap source of climate information. However, other conventional sources of information that farmers have increasingly used include TVs, the Internet, and other audiovisuals. The level of education among the farming household decision-makers affects their choice of CSA practices. For instance, Kinyua *et al.* (2022) found that small-scale farmers with higher levels of education had a higher likelihood of using agro-meteorological technology for input acquisition and adoption of CSA practices. Higher educational levels build the farmers' capacity to innovatively select useful farming information in the wake of the current climate change challenges. Moreover, education empowers households to access and interpret information effectively, enabling them to make innovative and informed decisions. (Owuor & Bebe, 2012).

Extension services among farmers have been revealed to be the best pathway of CSA as they promote these technologies, educate farmers on new frontiers of practicing modern farming, and help them easily access this farming information. Literature reveals that farmers who regularly use extension services for agriculture information dissemination sources had a higher chance of selecting the most effective CSA practices (Ayenew *et al.*, 2020). This is likely explained by the fact that farming households relying on extension services for farming information acquisition increase their awareness and exposure concerning the latest CSA technologies that are more practical and effective in tackling climate change shocks. Extension services offered through government agencies are inefficient because fewer extension officers are deployed to serve vast areas. The highlighted challenges have seen an increase in private organizations, including NGOs, offering extension services to farmers free of charge or at a fee. Kinyua *et al.* (2022) revealed that most farmers had to request extension services at a fee while some paid fuel costs to receive extension services from government-employed extension officers. Moreover, the county government extension officers had limited resources, such as training materials and insufficient means of transport to access the far areas, preventing them from effectively conducting frequent field visits. This has proven to affect CSA practices adoption by farmers negatively.

A study by Kabubo-Mariara and Mulwa (2019) on the adaptation to climate variability and its impact on the household food security in Kenya. The study used maize yield equivalent (MYE), which describes the farm production in equivalent quantities in kilograms of maize grain. A sample of 658 households obtained from 8 counties in Kenya was analyzed using the endogenous switching regression model. The findings from this study demonstrated that an increase in the mean air temperatures and precipitation could influence the levels of food production both positively and negatively depending on whether they happen at harvest, during land preparation, or the crop growth period. Furthermore, the results established that households living in places with different soil types produced additional quantities of MYE expressed in kg/ha or mg/ha. At the same time, the comparative analysis indicated that families adapting to climate change and variability through the uptake of new technologies, including crop diversification, improved crop varieties, and early planting produced significantly higher MYE/ ha per year than households that did not adapt to climate variability. The crop yield was a measure of food security since most small-scale households produced mainly for food consumption. The findings established that successful adaptation to climate change and variability increases food security in Kenya.

Bryan *et al*. (2013) investigated how agriculture in Kenya is adapting to climate change by conducting household surveys and participatory rural appraisals across various districts with different agro-ecological zones. Their study focused on farmers' perceptions of climate change, the adaptation strategies they employ, and the factors influencing their decisions. The findings revealed that most households made minor adjustments to their farming practices in response to climate change, with relatively few investing in more significant measures such as irrigation or agroforestry. The study suggested that increasing investment opportunities and supporting agricultural development are crucial for helping households make strategic, long-term decisions that enhance their future well-being. Additionally, Kibue *et al*. (2016) explored farmers' perceptions of climate variability and the factors influencing their adaptation strategies. The study utilized questionnaires to gather data from farmers in various agricultural regions and used climatological data to validate the farmers' perceptions of climate variability. The results showed that farmers' awareness of climate variability was consistent with climate records. However, the perceived impacts of climate variability varied between regions, reflecting differences in farmers' characteristics and local conditions.

Access to information improves farmers’ knowledge which is essential for adopting technologies. It helps farmers understand the different technologies available that can solve challenges faced during agricultural production and marketing. When farmers access information they can compare the available technologies more objectively and choose the best suitable technologies that will address their needs. The findings of Makamane *et al*. (2023) assert that access to information makes farmers more knowledgeable about CSA, hence adopting and using these practices to enhance their agricultural output. They noted a 33% increase in adoption by those who had information about CSA as compared to those who were not knowledgeable. These results agree with Serote *et al*. (2021) that smallholder farmers with the necessary knowledge of CSA technologies tend to have higher chances of adopting and using CSA practices in their farms for better agricultural output. Access to information also improved the perceptions of farmers towards climate variability hence enhancing adoption.

Jin *et al*. (2015) examined a gender difference in farmers' adaptation strategies to climate change in China. The study involved a random selection of 220 household heads, with data analyzed using binary logit models and descriptive statistics. The results revealed that, while there are gender differences in implementation of adaptation methods, the knowledge and perceptions of climate change between male and female respondents were largely similar. The results indicate that households led by men were more likely to invest in irrigation infrastructure and adopt new water-saving technologies. Gender emerged as a major factor in the adoption of Climate Smart Agriculture (CSA) practices, with women often facing constraints due to traditional gender roles (Wekesa *et al*., 2018). Further women have less access to important resources that can enhance the adoption of CSA practices. Such resources may include land, inputs, credit, education, and extension services with land ownership systems presenting more entrenched barriers to female-led households

Xie *et al.* (2022) conducted a study to understand how Northwest Chinese agro-pastoralists perceive climate change and related issues. A standardized questionnaire was used to gather data from 554 research participants across four counties in China's Gansu Province. Raw data was obtained using stratified random sampling. The respondents' perceptions of climate change and the associated socioeconomic and demographic factors were examined using a Probit model. According to the findings, 70% of the respondents had information on the variations in temperature and precipitation. Results indicated that agro-pastoralists understanding of climate change is directly correlated with socioeconomic and demographic factors, including gender, farming experience, education level, cultivated land size, agricultural income, livestock, village cadre experience, and access to meteorological information. On the other hand, the results established that the farmers' education level, farming experience, household size, grassland area, agricultural revenue, association membership, and village cadre experience strongly influenced agro-pastoralists capacity to adjust to climate change. The findings of this study were able to assist in directing governmental organizations and decision-makers as well as aid arid and semi-arid regions in developing sustainable adaptation strategies within the context of climate change.

Several factors influence the adoption of various agricultural inventions and technologies. Farm size is often cited as the first and most crucial predictor in empirical adoption literature. Farm size influences both the availability of information and the decisions regarding adoption (Gbetibouo, 2009; Marenya & Barrett, 2007). This is so because the other factors affecting adoption might also impact farm size and vice versa. Small- and large-scale farmers adopt particular technology at differing rates, moreover, land plays a crucial role in determining property rights and shaping long-term investments in climate change adaptation strategies. Land size and tenure security can influence the type of adoption technologies used such as capital-intensive and permanent practices irrigation equipment or soil conservation practices (Wekesa *et al*., 2018). The household size factor, which often explains the number of individuals living in one family, can be characterized from two aspects (Masela *et al.,* 2018). According to the first supposition made by Mwangi and Kariuki (2015), households with big families have access to cheap labour, which enables them to do various agricultural activities and removes the labour shortages needed to implement new technologies. The findings of Awinda (2018) assert that the availability of family labour enables the head of the home to share duties and free up time for other development-related activities.

Another important factor is the farmer's income from adoption after considering all new technology expenditures. This indicates the value added through the adoption of the technology in monetary tems. This is key in deciding whether to embrace new technology (Mwangi & Kariuki, 2015). Depending on its proportionate contribution to household or farm profitability, farm income can either positively or negatively influence technology adoption (Shange, 2015). According to Abegunde *et al.* (2020a), a substantial increase in farm income could significantly impact the adoption of climate-smart agriculture since it will allow farmers to buy the supplies they need. The majority of farmers in the Vhembe district said they would quickly adopt any innovations that would help them increase their income and output (Maponya & Mpandeli, 2012). However, the high cost of agricultural technologies has been found in research on technology adoption as a barrier to adoption (Mwangi & Kariuki, 2015). According to Chuchird *et al.* (2017), farmers had to pay for equipment, maintenance, and fuel, which resulted in a low farm income even after subtracting costs associated with utilizing the water pump.

Farm size affects decision-making since it may prevent farmers from using new technologies necessary for profitable agricultural endeavours (Abegunde *et al.,* 2020a). The results of numerous research that examined how farm size affected adoption decisions showed that the influence varied depending on variables, including fixed adoption costs, risk preferences, human capital, credit restrictions, labour needs, and tenure agreements, among other factors (Shaw, 2014). According to Faisal *et al.* (2019), the influence of farm size on technology adoption is ambiguous because it might have either a positive or negative effect.

The positive link is predicated on the idea that farmers with larger farm sizes produce more money, allowing them to have a greater capital base and improving their ability to take on more risk when implementing new technologies than their competitors (Shange, 2015). On the other hand, the negative link may be caused by the fact that farmers with limited resources may not be able to afford the high labour and input costs associated with cultivating bigger land areas (Myeni & Moeletsi, 2020).

CSA is recognized to be a key technique for both adaptation to climate change impacts and reducing greenhouse gas emissions. However, the adoption of CSA practices among small-scale farmers has been slower than anticipated, raising questions about the factors influencing its uptake within these agricultural systems. Abegunde *et al*. (2020a) in their study revealed that 56.6% of the surveyed farmers engaged in CSA practices at a moderate level, whereas only 17.7% employed CSA practices at a high level. The most frequently adopted CSA practices included the use of organic manure, crop rotation, and crop diversification. The research found that adoption of CSA techniques was significantly associated with various factors, including educational attainment, farm income, farming experience, farm size, interaction with extension services, media exposure, agricultural production activities, membership in agricultural groups, and perceptions of climate change impacts. Furthermore, the amount of CSA adoption was adversely connected with off-farm income and the distance from the farm to the farmhouse. The results implied that increased media exposure and extension contact could develop integrated agricultural activities, boosting farm profitability.

In their study Kassa and Abdi (2022) studied the determinants of adopting CSA practices by farmers in Southern Ethiopian region. The study used a mixed-method approach with about 213 randomly selected households. This study used an ordered logit regression model, descriptive statistics, and a composite score index for data analysis. The findings established that most of the farmers had a high knowledge of CSA methods, which helped them boost farm income and field productivity. The three CSA activities most prevalent in the research area were planting trees, using organic manure, and using irrigation systems. Moreover, the results showed that implementation of CSA by farmers was influenced statistically by education, size of the household, income, change perception of climate change, and farm size. However, the level of CSA adoption was negatively and significantly impacted by the separation between the farm and the farmhouse. The development and implementation of CSA programs for farmers should consider socioeconomic concerns.

A study by Aryal *et al.* (2018) where data was collected through surveys from about 1,267 households in about 25 villages in India. The study used a Multivariate Probit model to analyze simultaneous multiple adoption decisions. Furthermore, the study used an ordered Probit model to examine factors influencing the level of adoption. The findings from this study established that various CSA practices were interconnected, with household characteristics, farm characteristics, and market accessibility impacting the likelihood and level of CSA adoption. The results revealed that Eastern Bihar, which was relatively underdeveloped and heavily inhabited, and north-western Haryana exhibited quite different rates of adoption and intensity of climate-smart agriculture (CSA). For CSA to be widely adopted, it was necessary to involve various local stakeholders, including farmers, agricultural institutions, agricultural service providers, and interested government departments.

In their study on adaptation to climate change in the developing world, Adger *et al.* (2003) looked at societal vulnerabilities as a result of risks emanating from climate change. These could be social and climate challenges since society depends on some of these resources that are highly affected by climate change. Risks are evident in agriculture, fisheries, and numerous other industries supporting rural life in developing nations. This study examined the data on current development-country adaptation and coordinated global action for future adaptation. It is evident that all civilizations are inherently adaptable and that there have been several instances in the past where societies have done so in response to climatic changes and other similar hazards. However, certain industries are more sensitive to the threats posed by climate change than others as a result of some societal groups. Various cultures need to increase their ability to adapt to deal with current and future climate change outside their comfort zone. Climate change presents current development issues. Development agencies and governments are now preparing for this adaptation issue as a result of observed climate change, current climate variability, and future projections of change. Promoting adaptive capability in the context of conflicting sustainable development goals is a main challenge faced at both the size of local natural resource management and at the scale of international agreements and activities.

A study on adopting modern agricultural production technologies by households in Ghana discovered that the price of contemporary agricultural production methods was adversely correlated with their likelihood of adoption (Abunga *et al.*, 2012). However, it was determined to be unimportant since it indicates that the choice to embrace a new technology alters the investment possibilities available to farmers. This indicates that there is a low likelihood that a farmer will accept a technology if it is expensive to them. Additionally, farmers take into account the social cost of losing their livelihoods when making adoption decisions. For instance, a farmer whose primary source of income is maize farming will be hesitant to switch to enhanced groundnut cultivation for fear that the crop's failure will significantly impact their ability to support themselves. This explains why modern agricultural production technologies are not widely used in Ghana as a whole and in the research area since most farm households, typically small-scale operators, cannot afford the majority of the technology. The development of inexpensive technologies is a key component of efforts to promote the use of modern agricultural production technology, especially for the 90% of poor rural people who depend on agriculture for their living. Further, the findings established that market access and other institutional services affect adoption through transaction costs. While distance to the closest agricultural extension service center is used as a stand-in for institutional services, the distance to the village market is utilized as a proxy for market access. This is consistent with Chowdhury *et al.* (2014), who mentioned that enhancing acceptance and innovation requires access to institutional extension services.

An investigative study by Serote *et al.* (2021) established that smallholder farmers generally continue to use climate-smart irrigation technologies at a low rate. A face-to-face structured questionnaire was filled out by 100 smallholder farmers who were chosen using convenience and purposeful sampling. The decision of the smallholder farmer to adopt CSIT and the amount of adoption were examined using a Probit regression and OLS model. The findings indicated that less than half of the smallholder farmers implemented climate-smart irrigation technologies. This implied that factors including gender, age, location, farm size, production of basic foods, and CSIT awareness positively influenced adoption. The study recommended that key stakeholders improve extension services, offer training services, adopt robust crop varieties, promote underused and nutrient-dense crops adapted to challenging local conditions, and other interventions to reform the smallholder farmer subsector. This should be accomplished by raising smallholder farmers' awareness of the interventions and modern technology that may increase rural livelihoods, resilience, and adaptability.

In their study Justin *et al.* (2017) identified variables influencing Southern Malawi's adoption of various climate change adaptation measures. An ordered Probit model was estimated using survey data gathered during the 2014–2015 growing season in Nsanje and Balaka districts. It was discovered that factors like household head age, total land ownership, micro-enterprises, and formal employment decreased the likelihood of using more than two CSA techniques. The likelihood of using four CSA techniques was found to be lower among farmers who said they had observed changes in moisture levels in their regions over the 20 years before the survey than among those who said they had not. Being a lead farmer was significant because it implied having easy access to climate-smart agricultural extension. The likelihood of using more than two CSA techniques was enhanced by the availability of training, the amount of land used for agricultural output, and the observation of an increase in flood incidences over the 20 years preceding this study. It was interesting to discover that the number of CSA techniques adopted was unaffected by household income. The study suggests that if more farms are to adopt multiple CSA practices, relevant stakeholders should send out extension messaging linked to CSA to farmers.

A study by Sardar *et al.* (2021) examined the factors and estimated their benefits in terms of their influence on crop yield and farm income, the current study is intended to explore the adoption of CSA methods and their intensity. About 420 farmers were interviewed and a multinomial logistic regression was used to analyze data. Moreover, it controls the endogeneity issue and calculates the conditional impact on crop yield and farm income using a two-stage least square estimation method. The shows that institutional variables, finances, land size and education acquired by the farmers had major impact on the adoption of single to a full package of CSA methods. Similar to how more farmers who had experienced weather shocks expected to use CSA tactics. Results show that for the crops of cotton wheat and rice, respectively, farmers who adopted a full set of CSA practices saw higher production and farm revenue than non-adopted farmers. Additionally, the intensity of CSA practices used by the farmers affects how much of an impact adaptation has. The report makes useful recommendations for institutional and regulatory changes that will help farmers become more aware of CSA practices and receive financial support.

The environmental, economic, and social impacts of climate change are anticipated to be severe for coastal farmers, whose livelihoods are closely tied to the natural environment. Hassan *et al*. (2018) conducted a study to explore how coastal farmers perceive climate change and to identify barriers to the adoption of climate-smart agricultural practices. Data was collected from January to March 2018, involving 160 randomly selected farmers from four villages in the Kalapara sub-district of Patuakhali, Bangladesh. Information was obtained using a structured interview guide, and supplementary data were gathered through key informant interviews and focus group discussions with extension agents and farmers. A binary logistic regression model was used to analyze the factors affecting farmers' adaptation practices in response to climate change. The results indicated that factors such as the age of the household head, total land area, minor commerce, and formal employment were associated with a reduced likelihood of adopting multiple climate-smart agricultural techniques. The likelihood of using four CSA techniques was found to be lower among farmers who said they had observed changes in moisture levels in their regions over the 20 years before the survey than among those who said they had not. Interestingly, it was discovered that the number of CSA techniques adopted was unaffected by household income. Overall, this study advances knowledge of the variables influencing CSA sub-package uptake. The logit model's findings show that factors such as a farmer's level of education, occupation, family size, farm size, experience, ownership of cattle, annual income, access to the market, access to information, training, membership to a particular organization and perception of climate change all have an impact on the adaptation strategies they choose for the changing climate.

The above studies indicate that a lot of empirical research has been done over the years to determine what influences farmers' adoption of climate-smart agriculture (Teklewold *et al.,* 2013). Although CSA is a collection of strategies that farmers utilize in different combinations, the majority of recent research has solely examined the factors that influence one particular CSA strategy (Kuehne *et al.,* 2017). Farmers gain by using a variety of strategies since some of them are complementary and others can be used in place of others (Teklewold *et al.,* 2013). As a result, implementing different CSA approaches aids in creating a sustainable agricultural production system that is highly resistant to shocks connected to the climate and other factors. The lack of interest in implementing climate-smart agriculture (CSA) practices poses the issue of what factors determine adaptation to climate-smart practices.

### 2.10.2 Empirical literature on factors affecting uptake of climate-smart agricultural practices

Climate change poses a serious and growing threat to global food security, with Sub-Saharan Africa (SSA) particularly affected due to its limited capacity to adapt to climatic changes and variability (Wekesa *et al*., 2018). This issue is further aggravated by global climate shifts and increasing greenhouse gas (GHG) emissions, which both drive climate change and are intensified by agricultural practices. Smallholder farmers, who play a crucial role in the agricultural sector, are especially vulnerable to these changes. The unpredictability of climate patterns complicates their ability to plan and manage agricultural production effectively. In regions with arid and semi-arid lands (ASALs), smallholder farmers face significant challenges due to their dependence on traditional rain-fed farming systems. Their limited ability to adapt exacerbates their vulnerability to the severe impacts of climate change and variability (Kalele *et al*., 2021). Current climate impacts include erratic rainfall, unpredictable weather patterns, rising temperatures, frequent and severe droughts, and unusual occurrences of snow and thawing. These disruptions are significantly affecting agricultural productivity and making it increasingly difficult for smallholder farmers to sustain their livelihoods (Mogaka *et al*., 2021).

To tackle these challenges, Climate-smart agriculture (CSA) practices have emerged as a promising solution. CSA practices assist farmers in adapting to the adverse effects of climate change while also contributing to mitigation efforts. Some CSA techniques act as carbon sinks, which helps reduce greenhouse gas levels in the atmosphere. By adopting CSA practices, farmers can enhance their resilience to climate shocks and contribute to broader environmental and climate goals.

Climate-smart agriculture (CSA) is increasingly recognized as a key strategy for maintaining robust food production while tackling environmental challenges, climate change, and global greenhouse gas emissions. CSA practices play a crucial role in enhancing the adaptability of smallholder farmers, thereby protecting their livelihoods and ensuring food security (Wekesa *et al*., 2018). These practices involve the strategic management of natural resources, the adoption of sustainable farming techniques, and the optimization of agricultural production, processing, and marketability. For instance, employing improved crop varieties, organic fertilizers, and advanced postharvest techniques can elevate product quality, leading to better market prices. Agroforestry, another important CSA practice, helps mitigate smallholder farmers' vulnerability to climate change by acting as a carbon sink, reducing soil erosion, and supporting sustainable land use (Beyene *et al*., 2019). Additionally, practices such as organic farming and mulching enhance soil structure and moisture retention while sequestering carbon. Intercropping is a valuable CSA method that optimizes land use and reduces the risk of complete crop failure due to climatic variability (Mogaka *et al*., 2021). The focus on sustainable development within African agriculture has led to an increased adoption of CSA practices among small-scale farmers. Other CSA strategies include integrated pest management, cover cropping, integrated crop-livestock systems, traditional organic farming, crop rotation, conservation agriculture, water conservation techniques, drought-tolerant crop varieties and breeds, crop diversification, and risk insurance (Mazhar *et al*., 2021). Together, these practices contribute to building a more resilient and sustainable agricultural system

The Climate-Smart Agriculture (CSA) approach has emerged as a promising strategy for boosting farm productivity in the context of climate change. The choice of CSA practices by farmers is shaped by a variety of factors, including socioeconomic conditions, land characteristics, and institutional influences (Kalele *et al*., 2021; Mutunga *et al*., 2018). Key advantages of CSA technologies include their capacity to enhance land use efficiency, conserve soil and water, and manage waste effectively in response to shifting climate conditions. Despite their critical role in agricultural production, there has been considerable research into the factors that determine the adoption of CSA practices (Talanow *et al*., 2021). Several factors influence the selection and adoption of CSA practices. For instance, the age of the farming decision-maker, the size of land cultivated, land tenure arrangements, and proximity to markets all impact the choice of CSA practices (Beyene *et al*., 2019). Additionally, factors such as educational level, household income, farming experience, and access to extension services are crucial in determining the adoption of these practices (Mogaka *et al*., 2021). The adoption rates of CSA practices can vary significantly depending on regional conditions and the scale of farming operations, with notable differences between small-scale and large-scale producers.

Climate-Smart Agriculture (CSA) offers an effective, reliable, and sustainable method for increasing resilience and addressing environmental challenges (FAO, 2010). CSA strategies are designed to bolster resilience to climate variability while simultaneously reducing greenhouse gas emissions, thereby promoting sustainable agricultural productivity and improving farm incomes (FAO, 2013). Research by Sapkota *et al.* (2015) highlights that Conservation Agriculture (CA) systems can lower production costs by up to 23% while maintaining or even improving yields compared to traditional farming methods. Furthermore, a study conducted by Khatri-Chhetri *et al.* (2016) found that adopting CSA practices, such as improved seed varieties, zero tillage, and laser land levelling, resulted in significant yield improvements for rice and wheat 19%, 6%, and 610% respectively. Notably, the zero tillage technique alone led to a reduction in input costs of up to 41%. CSA's core objective is to manage climate variability effectively to enhance food security (Lipper *et al.*, 2014). Beyond environmental conservation, CSA practices not only boost agricultural productivity but also fortify the resilience of farming communities against the negative impacts of climate variability.

The adoption of CSA helps achieve high levels of adaptive capacity by ensuring efficient resource usage and developing farming systems that can adapt to climate change shocks (Lipper *et al.*, 2014). Each CSA technology has its advantages and disadvantages; for instance, adopting conservation agriculture has improved farmers' yields and their welfare, while agroforestry has been observed to increase farming households' income, livestock holdings, and household nutrition. Some likely reasons for low levels of CSA adoption, especially among small-scale farming households, include insufficient access to farmland, labour related challenges in implementing these practices, and inadequate financial capital for implementing CSA technologies (Brown *et al.*, 2018). Conservation agriculture (CA) is one of the CSA techniques widely promoted as part of sustainable farming intensification processes in most grain farming regions of developing countries, such as those in SSA. Through a broader inspection of the level of adoption of CA beyond the binary approach of adoption or non-adoption, therefore it is important to reassess the expectation of the uptake of several CSA practices among smallholder farmers to establish the possible relationships between different CSA techniques which can inform complementarity or substitutability. A study by Brown *et al.* (2018) reveals a low uptake of CSA practices among small-scale farmers in the SSA, possibly explained by the lack of financial stimulation among farming households. Moreover, when farmers join producer/ farmer organizations, farmers are most likely to acquire solid collaborative skills and build more synergy in CSA implementation.

Conservation agriculture (CA) combines several practices for the common good of the farmer; for instance, it encompasses the simultaneous adoption of minimum soil disturbance in the crop fields, the establishment of permanent cover crops to protect the soils, and the practice of crop diversification strategies (FAO, 2020). The pathways to CA are complex to implement; however, its adoption among farming households enables them to benefit more from these CSA approaches. Diverse adoption of CA has the advantage and potential for agronomic adoption to any agricultural zone; however, this is subject to factors such as socioeconomic and political circumstances that inform the need to modify CA to fit local scenarios (Brown *et al.,* 2018). Therefore, African climate policy should prioritize empowering small-scale producers to lower vulnerabilities and adapt to climate change and its effects by adopting a combination of effective CSA practices.

Farming households' response to the effects of climate change in different farming regions, especially the small-scale rural producers, coupled with intervention by civil society and other international organizations, reveals the capability for innovation to adopt CSA technology globally. The African farming system reveals more vulnerability to climate change's adverse effects than other regions. The possible explanation for the highlighted observation by Field *et al.* (2014) intimates that Africa already faces a harsh climate characterized by low and inadequate precipitation, flooding in some areas, and high temperatures. The impacts of all these are exacerbated by the common utilization of irrigation opportunities and low uptake of CSA technologies attributed to poor economic conditions of the SSA countries (FAO, 2020). The level of uptake of CSA practices as a systematic approach in the wake of climate change and its vulnerabilities is faced with other challenges, as discussed below.

Limited access to farming equipment tailored toward the effective implementation of CSA techniques is a significant shortcoming against CSA adoption in Africa (Ojoko *et al.,* 2017). Ideally, CSA practices do not require complex equipment compared to conventional farming systems. However, some CSA practices need context-specific farm equipment to be adopted and implemented successfully. Therefore, if this equipment is unavailable, the adoption of certain CSA practices cannot be realized. Typically, the variation in farm equipment utilization occurs in farming field preparation and seeding. Therefore, depending on the farmer's contextual need, some farming equipment utilized in conventional farming could be used for CSA practices. In contrast, others need some degree of modification for practical use in the agricultural fields (Kaptymer *et al.,* 2019). This results in additional costs incurred by the farmer in modifying the equipment which sometimes discourages most farmers from adopting CSA practices

Some CSA benefits are facilitating high farm productivity through farming management activities that enhance soil fertility and provide pest and weed utilization with little or no use of agricultural chemicals that harm human beings, animals, and the ecosystem. However, constraints in accessing the highlighted farm inputs, such as seeds, pesticides, herbicides, and fertilizers, limit the successful implementation of CSA technologies in African farming systems (Kaptymer *et al.,* 2019). Moreover, CSA adoption guarantees more long-term benefits than conventional agriculture, which mostly features short-term benefits. Most smallholder farmers have inadequate access to agricultural finances/funding; therefore, purchasing farming equipment, agricultural inputs, and hiring farm labour is hampered. Most farmers also prefer instant impact as compared to long term impact especially if they are hiring land which they may not be using for a long period of time.

According to Makate (2019), attaining long-term CSA benefits requires high initial investment costs, which could be expensive for most small-scale farming households. Additionally, some CSA practices have immediate benefits, while others manifest their benefits after a more extended period. For instance, while some farmers could realize CSA practices' advantages within the first year of adoption, others may wait for 3-7 years. The farmers who need to wait longer to benefit from adopting the later CSA practices are more likely to avoid the technology and embrace the earlier CSA practices. These farmers can adopt long-term CSA techniques if they have initial funding to invest in the technology. They will benefit in the first or second year of implementation (Knaepen *et al.,* 2015).

Looking at the socioeconomic constraints, farmers in many parts of SSA, especially the small-scale producers, are exposed to inadequate land and water for farm irrigation and have weak and unsecured rights to land and water. Factors such as typical and institutional characteristics of the society from which the small-scale farmers come always hinder adopting CSA practices, especially the long-term technologies. Additionally, new investors (development promoters) such as large-scale production/investment result in the displacement of small-scale farming households, further limiting their adoption of CSA technologies (Williams *et al.*, 2012). Moreover, small-scale farming households do not have access to domestic, regional, or international commodities markets. Other factors, such as low information/awareness concerning CSA practices and extension services, limit farmers' ability to assess the risks and benefits of CSA practices (Abegunde *et al.*, 2020). Labour availability is an important driving force in the agricultural production system, especially in the SSA; however, labour demand in many countries of Africa most often overrides the available supply. The highlighted issue contributes to a significant challenge in the farming system, especially the small-scale farming households. Labour availability for farm production processes is impacted by youth participation in farming, rural-to-urban migration of potential labour force, depreciation and wearing down of farm equipment, malnutrition, and poor wage rate (Abegunde *et al.*, 2020). Some CSA practices may require high labour utilization; such tasks might demand more labour for their establishment.

Agricultural practices that use the CSA approach for weeding and land preparation demand more human resources than available labour. In this regard, farmers will either work with more delivery or use herbicide as a substitute for labour (Ojoko *et al.*, 2017). Another example of CSA practices that demand more labour is the establishment of Zai pits. Zai pits are a conservation practice used to conserve soil moisture, hence improving soil fertility, but they require high human resources for their implementation. There is an enhanced adoption of this technology reported in West, East, and Southern Africa (Kaptymer *et al.*, 2019). However, this innovation requires increased funding and labour requirements, therefore becoming a setback in its adoption.

Data unavailability, poor analytical tools, and a good understanding of CSA technology are revealed as some of the features challenging the uptake of CSA technology among many SSA countries. In some instances, inadequate data on many issues of concern prevents proper utilization of the highlighted farming technology. In cases where data exist, they are not openly available for use since they are scattered all over the various sources of storage or not retrievable at ease. There is insufficient long-term data on the climatic phenomenon and ecosystem. The available models for climate change are not context-specific to an area such as local, national, or regional level. Still, they represent the climatic condition globally, therefore likely to give misleading estimates for interpretation (Makate, 2019).

The age of the household head reflects their experience, allowing farmers to observe and compare changes over time with current climatic conditions. This increases the likelihood of perceiving climate variability due to their past experiences coupled with the current climatic conditions (Atsiaya *et al.,* 2019). Gender of the head of the household significantly impacts responses to climate variability, with male heads generally having better access to information compared to female heads (Mugi-Ngenga *et al*., 2016). This disparity is often attributed to traditional barriers that limit women's rights to essential production resources, with land being a primary example. Research by Oluwakemi *et al*. (2014) reveals a positive correlation between gender and adaptation strategies, indicating that male farmers are more inclined to adjust planting periods in response to climate variability, rather than focusing on soil and water conservation methods. Educational attainment enhances farmers' exposure to and capacity for processing and utilizing information pertinent to climate change adaptation (Atsiaya *et al*., 2019). Access to agrometeorological information influences farmers' attitudes and their willingness to integrate both traditional and modern practices, thereby improving their ability to make well-informed decisions (Dinku *et al*., 2014). Moreover, better access to extension services facilitates information availability and enhances knowledge about various management practices for climate change adaptation. Social capital also plays a crucial role by improving information access, fostering social trust, and enabling farmers to rely on information shared within their community. This, in turn, affects their behavior and responsiveness to climate challenges (Frankenberger *et al*., 2013).

### 2.10.3 Effect of adaptation to climate variability on agricultural productivity

Climate change is a global concern and farmers are taking different adaptation strategies to adapt to its negative impacts (Soglo & Nonvide, 2019). A study in Benin revealed that almost all the studied farmers acknowledged climate change as a climate change variable. Socio-economic and institutional factors such as age gender marital status, education, experience in maize production, access to credit, TV ownership, and agricultural training were the major determinants of adaptation strategies. Some of the strategies the maize farmers employed included adjustment of sowing time, use of improved crop varieties, and integrating of livestock and agroforestry. The study suggests that combining agrometeorological information services and indigenous knowledge will help farmers adapt better to weather variability. Promotion of reforestation and agroforestry were identified techniques that would enable farmers to cope with the harmful effects of strong winds and improve soil fertility. Using the same variables this study determined how they influence adaptation of climate change strategies.

Yam production by smallholder farmers in Nigeria is vulnerable to effects of climate change Samuel *et al.* (2018), examined the effect of climate change on root crop production in

Cross River State, Nigeria. The study used a sample design of 150 farmers. A Likert rating scale and descriptive statistics were used to analyze the objective. The study findings indicated that climate variability and change had effects on yam production. Some of the factors contributing to poor productivity include increased losses due to diseases emanating from climate change and the cost of excess rainfall. Income from yams was used as a proxy to capture productivity from yam production. Empirical results indicate that a unit increase in losses from yam, diseases decreased farmers' income by 1.31.

Although maize production in the Northeast Farming Region of China has shown increasing trends over the last decades, there has been observed inter-annual fluctuation. This fluctuation was a result of increased variation in local temperature and high rainfall patterns in the maize-dominant region. In assessing future maize production under multiple climate change scenarios in the Northeast Farming Region of China, Tian *et al.* (2020) used a cross-scale simulation tool. The results indicated that the adaptation of maize cultivars and changing planting/harvesting dates, planting area, and yield per unit area increased in the Northeast Farming Region of China. Adaptation of these practices was observed to help farmers take advantage of increasing heat from global warming and avoid maize losses. Using the ESR model, this study indicated how climate change-related factors can be exploited through the use of technologies to improve crop productivity. Kogo *et al.* (2021) indicate that climate change and variability pose a major threat to the agricultural sector globally. In their study, they examined crop production and food security in Kenya under variable climate. Their study acknowledges that the country is experiencing episodes of climate change, which is manifested by seasonal changes in precipitation and temperature of varying severity. These change in climate variability alters cropping patterns and yields. Crop production and food security systems should be adaptive to sustain high populations and rapid urbanization.

Climate-smart agriculture practices, such as drought-resistant maize and enhanced legume varieties, are crucial for managing climate change, especially for smallholder farmers in southern Africa (Makate *et al*., 2019). This research investigated the factors that influence the adoption of these climate management strategies and evaluated their impact on crop productivity and farmer income. By employing multinomial logistic regression and regression adjustment with inverse probability weighting, the study analyzed how various adoption scenarios affect farm productivity and income. The results reveal that integrating these climate-smart practices with supportive institutional and policy measures significantly improves their effectiveness. The study further demonstrates that combining conservation agriculture with stress-tolerant legume varieties and drought-resistant maize as a comprehensive approach leads to greater productivity and higher incomes than adopting these practices individually (Khonje *et al*., 2018).

The combination of traditional agricultural methods with rising input use and climate change poses a significant challenge to agricultural production in developing countries (Rehman *et al*., 2019). Consequently, embracing Climate-Smart Agriculture (CSA) is crucial. Jamil *et al*. (2021) conducted a study using cross-sectional data from 350 cotton farmers who implemented CSA practices, including irrigation and advanced soil and crop management techniques. By employing logistic regression and propensity score matching models, the study assessed the impact of these practices on poverty, income, and yield. The findings demonstrated that CSA practices are not only economically viable but also financially advantageous, environmentally beneficial, and supportive of poverty reduction. The adoption of CSA practices was shown to mitigate the adverse effects of climate change, leading to increased productivity and profitability for cotton farmers. (Ali *et al*., 2018; Raza *et al*., 2019). With increasing climate variability, and diminishing resources and to ensure sustainable agricultural productivity, it is important to adopt CSA practices. Adoption of these CSA practices should also be done in line with relevant policies and considerable changes in national and local governance (Aryal *et al.*, 2020). Therefore, the removal of barriers in the adoption, dissemination of information regarding CSA, and strict enforcement are important in achieving agricultural productivity and resilience among farmers in a climate changing environment.

Climate related risks are correlated to low productivity, food insecurity, and poverty and due to differences in agricultural production areas, not all CSA practices can suit everywhere (Venkatramanan & Shah, 2019). This shows that some CSA practices may be very effective in some areas and not effective in others depending on the suitability. The heavily promoted CSA practices have been lowly adopted in Africa despite being promising. Makate, (2019) alludes that the low adoption challenge can be solved through prudent policy and institutional efforts that can improve the scaling up of CSA practices. The study emphasizes that scaling up of CSA practices and technologies is not autonomous hence facilitation for conducive policy and institutional actions are required. The study did not indicate that some of the CSA practices are area specific which can lead to low adoption rates by farmers.

Business-as-usual practices for farming under climate change regimes indicate that the agricultural sector is likely to be impacted by its effects such as increased temperatures and shifting precipitation patterns (de Pinto *et al.,* 2020). The paper indicates that adopting CSA can contribute to increasing agricultural production under unfavourable climate conditions while contributing to mitigating GHG. Phiri and Mungatana (2021) employed a conditional logit model to investigate how drought conditions influence the adoption of agricultural practices. Their study revealed that under drought scenarios, the adoption rates for organic manure and water conservation practices increased by 76% and 29%, respectively. Additionally, the research found that integrating organic manure with inorganic fertilizers enhanced maize production efficiency by 18%, with the effect being more pronounced among households affected by drought. In another study, Kurgat *et al.* (2020) examined the factors influencing the adoption of five different agricultural technologies aimed at boosting productivity and resilience among smallholder farmers in Tanzania. This study utilized data from 821 farming households to identify the key determinants driving the adoption of these technologies. The findings indicate that the adoption of climate variability through practicing CSA practices improved food availability at the same time reducing the impacts of climate change. This finding corroborates those of Asrat and Simane (2017) who found that those farmers who adopted and maintained CSA practices on their farms in the years 2015 and 2017 increased farm level production by 22% compared to non-adopters. This result signified climate related risks had a direct effect on the yield variability.

Adaption to climate change variability through the adoption of CSA practices has been observed to have several benefits in addition to agricultural productivity. For instance, the adoption of agroforestry benefits farmers through reduced soil and water erosion, improvement of water management, and reduced crop yield variability. In their study, Gashure *et al.* (2022) used multiple linear regression and the ESR models. This study revealed that the adoption of CSA practices such as crop diversification, terracing, organic manure, and rainwater harvesting showed a significant increase in crop production. For instance, the adoption of terraces as a climate change mitigation measure had a positive effect on sorghum yield. This study, therefore, using the ESR model aimed to evaluate whether farmers adopting these CSA practices had the same results or contradicted these findings.

## 2.11 Theoretical framework

### 2.11.1 Technology acceptance model (TAM)

Davis developed the Technology Acceptance Model (TAM) (Davis, 1987), from technology acceptance model to research on the factors affecting the use of mobile phones in rural Bangladesh. The Technology Acceptance Model is designed to specify the relationships between system design features, perceived usefulness, perceived ease of use, attitude towards using the technology and actual usage behaviour. It combines different aspects of other theories such as diffusion of innovation theory and theory of reasoned action. This theory explains major factors that determine information technology usage or rejection. These factors include external factors (facilitating conditions and tech-service promotion), individual factors (demographic, individual characteristics and social influence), perceived ease of use, perceived usefulness, technology service attributes and behavioural intention. The theory assumes that social influence is more important than the technology itself in determining technology usage. In this study the acceptance of CSA practices can be influenced by external factors which may include policies, infrastructure and support services. It may also be influenced by individual factors which could be the perception of the potential user and influence from the social networks. The perceived ease of implementing and perceived usefulness of the strategies may also influence the acceptance of specific CSA practices. Finally, how the farmer will be satisfied after implementing the practice will have a multiplier effect by influencing adoption by other farmers. Therefore, this theory is relevant to this study as it helps understand the factors that influence the choice of climate smart agricultural practices to be used.

### 2.11.2 Protection motivation theory

Rogers (1983) introduced Protection Motivation Theory (PMT) as an expansion of the health belief model. This theory explores why individuals take protective actions in response to perceived threats. According to PMT, defense motivations arise from a thorough evaluation of both the threats and the available coping strategies. Assessing the danger involves evaluating the threat's severity and the individual's vulnerability. Perceived severity pertains to how serious individuals believe the threat is, while perceived vulnerability relates to their sense of personal susceptibility to the threat (Bockarjova & Steg, 2014). For example, in the context of climate variability, perceived severity would reflect the harmful impacts of climate change on smallholder sorghum farmers, whereas perceived vulnerability would denote their sensitivity to these adverse effects on sorghum cultivation. PMT also includes three key components in coping evaluation: self-efficacy, response efficacy, and response cost. Response efficacy is the belief in the effectiveness of a recommended action in mitigating a threat. Self-efficacy refers to an individual’s confidence in their ability to perform the recommended coping action (Yoon *et al*., 2012). Response cost encompasses all perceived costs associated with adopting preventive measures or adaptation strategies, including both monetary and non-monetary factors such as time, effort, and inconvenience (Bockarjova & Steg, 2014).

Westcott *et al.* (2017) assert that Protection Motivation Theory (PMT) is applicable to any situation where individuals might adopt an effective response to a perceived threat. The theory has also been effectively utilized to analyze smallholder farmers' pro-environmental behaviors (PEBs) (Keshavarz & Karami, 2016). This makes PMT particularly relevant for examining how smallholder farmers adopt adaptation measures in response to climate variability threats. Research by Wang *et al*. (2019) indicates that farmers' environmental behavior is significantly influenced by response costs, as they often face shortages of essential resources and limited financial resources. Consequently, high response costs can negatively impact their willingness to adopt certain practices. Increased awareness of risks typically enhances perceptions of severity and vulnerability. Farmers who view climate variability as a serious threat to their agricultural productivity and livelihoods are more likely to adopt adaptation strategies such as agroforestry, crop rotation, rainwater harvesting, cover cropping, mulching, using organic manure, and planting drought-resistant crops like sorghum.

**2.11.3 Utility maximization theory**

Farmers are willing to make and pay for preferences that maximize their utility. Utility is defined as a function of both market goods, denoted as *x*, and non-market items denoted as $q$. The utility function for an individual may be written as $u(x,q)$ and the utility is maximised subject to income y. the direct utility function is therefore given by:

$$\mathrm{V(p,q,y)} = \max\{u(x.p)|p.x \leq y\} \quad \ldots\ldots 1$$

The indirect utility function depends on prices of market goods, *p*; an income of an individual, *y*; individual characteristics, *s*; and stochastic component, *e*, representing the notion of random utility maximization. Indirect utility function can be written as: $v(p,q,y,s,e)$. An individual maximizes utility subject to income y. The indirect utility function $v(p,q,y,s,e)$ is as shown in equation 2.

$$v(p,q,y,s,e) = \max\{u(x,p) \mid p,x \leq y\} \quad \ldots\ldots 2$$

The characteristics of the indirect utility function and the expenditure function are well established in economic theory (Deaton and Muellbauer, 1980). The expenditure function's derivative provides the Hicksian (or utility-constant, compensated) demand function, denoted by the appropriate subscript to indicate partial differentiation. Conversely, the Marshallian (or ordinary) demand function is derived from the negative ratio of the derivatives of the indirect utility function. This relationship is represented by equation 3

$$u_i(p,q,u) = mp_i(p,q,u) \quad \ldots\ldots 3$$

The decision on choice of agrometeorological information pathway and uptake of CSA strategies is based on the utility derived from the information received through the pathway and the uptake of response strategies. The utility function normally reflects the good or a service together with social and demographic characteristics that contribute to the utility of the respondent as presented in equation.

$$u = v(p, q, y, s) + e = v + e \quad \ldots 4$$

where $u$ represents utility of individual choosing a product, $v$ the deterministic component of indirect utility, $y$ the level of individual's income, $s$ the factors that could affect the utility of individual and $e$ the random component of the utility function. Uptake measures the level to which an individual implements CSA practices measured through the number of practices implemented by the farmer for an improvement in their circumstances (utility maximization) or number of practices an individual is willing to implement to avoid the adverse effects of climate change. Willingness to pay is defined using the indirect utility function as shown in equation.

$$v(p, q * s, y - WTP) = v(p, q, y) \quad \ldots 5$$

where $v$ denotes the indirect utility function, $y$ the level of individual income, $p$ a vector of prices faced by the individual, and $q*$ and $q$ are the quantity indexes or alternative levels of good with $q^* > q$, and increases in $q*$ is advantageous since $\frac{\partial v}{\partial q} > 0$, implying that higher consumption level of $q^*$ leads to higher utility.

## 2.12 Conceptual framework

The national agro meteorological service should be composed of scientists/experts capable of analysing data from a variety of sources, including satellites, processing and packaging it in accessible formats in order to improve agro meteorological forecasting. Relevant awareness is one of the criteria for effective packaging. In this situation, experience requires an understanding of how other people speak like scientific terms, knowledge of the subject matter (meteorology), and general knowledge. If smallholder farmers or end users are unfamiliar with the issue, information must be packaged in an easily understandable manner.

The agro meteorological information dissemination pathways should ensure that the packaged message is delivered through the appropriate medium or communication channel. Meteorological services should ensure that farmers understand how to interpret weather forecasts. For successful communication, those who disseminate knowledge should understand the shared sense between scientists and farmers. Access to and efficient use of agro meteorological knowledge by smallholder farmers are critical for increasing agricultural productivity. Climate forecasting capabilities can be limited by factors such as age, gender, literacy levels, and the availability of extension services and packaging of such knowledge for use by farmers.

The accuracy and significance of agro meteorological data are meaningless if the affected farmers lack decision-making options. Appropriate draft control, sources of income, crop cultivars, irrigation, and fertilizers will all be accessible. Identifying these choices is critical for farmers to learn how to use and benefit from climate forecasts. To increase productivity, one alternative would be to improve farmers' access to and effective use of agro meteorological information by identifying and resolving the issues affecting access to and use of agricultural information. This can be accomplished by examining the socioeconomic factors, institutional factors and climate related factors that could have a major influence on knowledge access and utilization. The study's conceptual framework is predicated on the premise that access to and use of agro meteorological information.

While there are various channels through which farmers can access agrometeorological information, the effective adoption of Climate-Smart Agriculture (CSA) practices is often hindered by several factors over time. These constraints stem from various external influences that affect the choice of dissemination methods, access to information, and adaptation to climate variability, as illustrated in Figure 1. These external factors can be categorized into socio-economic, climate-related, and institutional elements. Each of these factors plays a role in shaping how farmers select specific pathways for receiving agrometeorological information, their ability to access this information, and their overall adaptation strategies to climate variability and change. Addressing these factors is crucial for enhancing farmers' livelihoods by improving household resilience, bolstering local and national food security, and increasing income levels.

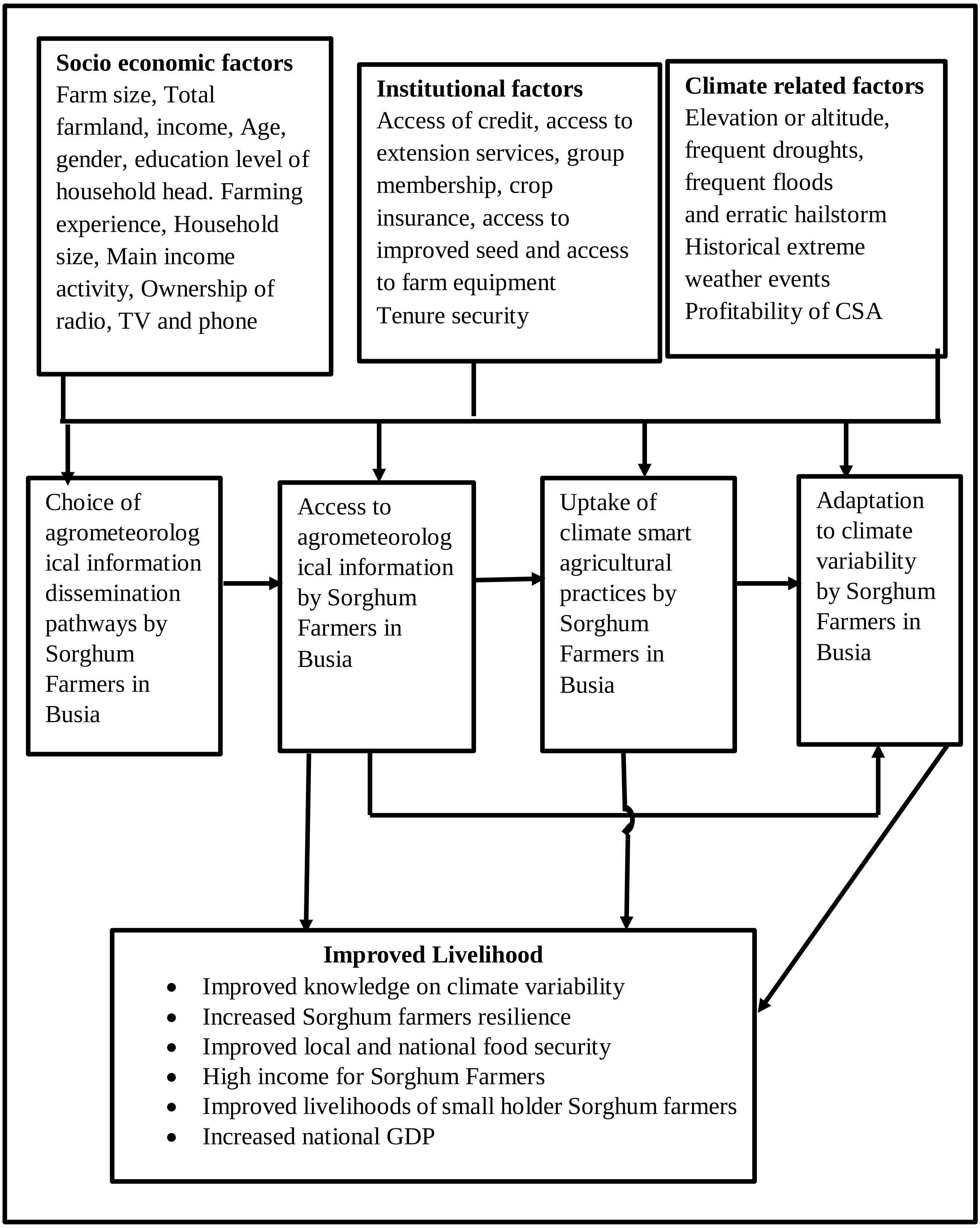


**Figure 2. 1** Conceptual Framework

# CHAPTER THREE

# METHODOLOGY

## 3.1 Study area

The research was carried out in Busia County, situated in the western part of Kenya between latitudes 0º and 0º 45' North and longitudes 34º 25' East (see Figure 3.1). The county spans approximately 1695 square kilometers (KNBS, 2013) and is bordered by Siaya to the southwest, Bungoma to the north, Kakamega to the east, Lake Victoria to the southeast, and Uganda to the west. The average temperature in Busia County ranges from 21 to 27°C (Wanyama, 2018), with annual rainfall varying between 750 and 2000 mm. Rainfall distribution differs across the county: areas near Lake Victoria receive the lowest amount, around 760 to 1015 mm, while regions like Butula and Nambale experience higher rainfall, reaching up to 2000 mm. The rainfall pattern is bimodal, with the long rains occurring from March to May and the short rains from August to October. Elevations in the county range from 1,140 to 1,500 meters above sea level, providing favourable conditions for agriculture. The primary agricultural activities in Busia include growing crops such as cassava, sorghum, maize, groundnuts, sugar cane, and various horticultural crops like local vegetables and mangoes, as well as livestock and fish farming (Ng'endo *et al.*, 2018). Despite its significant agricultural potential, the county is notably impacted by climate change.

Busia County stands out as one of Kenya's leading sorghum producers, with cultivation taking place predominantly on smallholder farms averaging 1-2 acres throughout the region. Sorghum is favored for its high yield and drought tolerance, thriving in both semi-arid and moist mid-altitude areas. It also boasts excellent brewing qualities and resistance to smut disease. Between 2012 and 2014, the area dedicated to sorghum production in Busia grew significantly by 71%, reaching 13,109 hectares (Githinji *et al.*, 2020). This substantial increase was largely fueled by East African Breweries Limited's (EABL) initiative, launched in 2012, to source all of its sorghum requirements domestically from within Kenya. The choice of Busia was influenced by its sensitive environmental conditions and susceptibility to climatic fluctuations. The recurrent droughts in Samia and Teso North, along with the low productivity associated with small, uneconomical land holdings, have exacerbated the impacts of climate variability, affecting the livelihoods of local communities. In response, farmers are seeking innovative solutions to address these climate challenges, with agrometeorological information playing a crucial role in developing practical strategies.

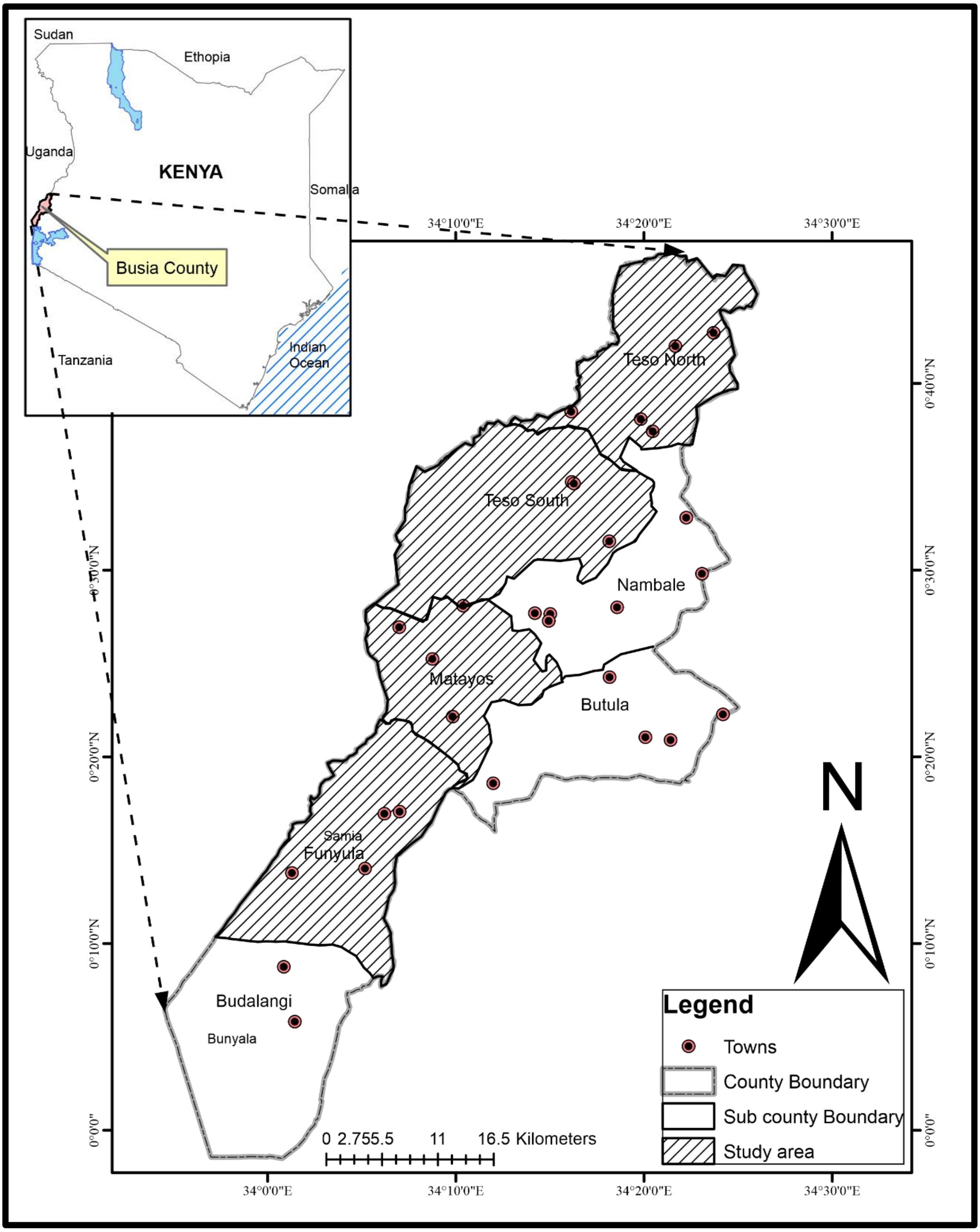


**Figure 3. 1** Map of Study Area (Busia County)

**Source:** Egerton University Geography Department

Busia County is divided into sub-counties, including Teso North, Teso South, Butula, Nambale, Matayos, Samia, and Budalangi. The primary sorghum-producing areas are Teso South, Teso North, Matayos, and Samia (Nyongesa *et al*., 2017). Therefore, the study focused on Teso South, Teso North, Matayos, and Samia sub-counties, as these are the key regions for sorghum production (Nyongesa *et al.,* 2017).

### 3.2 Sampling procedure

The study employed a multi-stage sampling approach, focusing on Busia County due to its susceptibility to climate variability and its prominence as a sorghum-producing region. From the seven sub-counties in Busia, four Teso South, Teso North, Matayos, and Samia were intentionally selected as they are the primary areas for sorghum cultivation (BCIDP, 2018). Within each selected sub-county, sorghum farming households were chosen through a systematic sampling method. This involved selecting households from a pre-compiled list of farmers obtained during a preliminary visit. The selection process included prequalifying sorghum farmers based on their land size and duration of sorghum cultivation.

### 3.3 Sample size determination

A representative sample of smallholder farmers was drawn to reflect the population of smallholder sorghum farmers in Busia County. The focus was on sorghum farmers from the sub-counties of Teso South, Teso North, Matayos, and Samia. Given that the exact number of smallholder sorghum farmers was not available, the sample size was calculated using Cochran's (2007) formula, as detailed below:

$$n = \frac{pqz^2}{E^2} \qquad (6)$$

where; n = sample size; Z= confidence level (α=0.05); p = proportion of the population containing the major interest; while q = 1-p; and E= allowable error. Since the proportion of the population is not known, p = 0.5, q = 1- 0.5 = 0.5, Z = 1.96 and E (allowable error) = 0.05 because the study allows a 95% confidence level.

$$n = \frac{0.5 \times 0.5 \times 1.96^2}{0.05^2} = 384 \qquad (7)$$

The sample size, calculated using Equation 2, was increased by 10% to account for potential data loss or uncooperative respondents, resulting in a total of 423 sorghum farming households. This adjustment ensured that the minimum required sample size was maintained despite any issues encountered during data collection and cleaning. The distribution of the sample size across the sub-counties was done proportionally based on the population size, using lists of farmers obtained from the agricultural offices in each sub-county (Table 3.1)

**Table 3. 1** Sample size distribution per Sub-County

| Sub-county | Number of farming households in the sub county | Proportionate distribution formula | Sample size |
|---|---|---|---|
| Teso North | 17,182 | 17,182 *423/81,350 | 90 |
| Teso South | 26,895 | 26,895*423/81,350 | 140 |
| Matayos | 16,539 | 16,539*423/81,350 | 85 |
| Samia | 20,734 | 20,734*423/81,350 | 108 |
| Total | 81,350 | Total | 423 |

### 3.4 Data and collection methods

The study employed a semi-structured questionnaire to collect primary data from smallholder sorghum farmers. To validate the questionnaire, a pilot study was conducted in Nambale Sub County. Following Connelly's (2008) recommendation for a pilot study involving 10% of the intended sample size, 42 smallholder sorghum farmers were selected for this initial phase. The pilot study aimed to assess the questionnaire's validity and determine the time needed for its completion. Trained enumerators, skilled in agricultural and household data collection, conducted face-to-face interviews using the questionnaire, which comprised both open and closed-ended questions. Data collection was managed digitally via the Open Data Kit (ODK) application. The interviews focused on farm and farmer characteristics, institutional factors, production practices, climate conditions, and market-related issues. The gathered data was then processed and analyzed using STATA software (Version 16).

### 3.5 Analytical technique

**Objective 1**: **Econometric modelling of factors influencing the choice of agrometeorological information access pathways among smallholder sorghum farmers in Busia County**

Smallholder sorghum farmers’ choice of agrometeorological information pathways is inherently a Multivariate decision. There are several dissemination pathways, and the decision to use one information pathway may not be mutually exclusive to selecting another pathway; hence the choice for selecting agrometeorological dissemination pathways may be correlated. There are several models that can be used in this analysis including binary response models, univariate model and multivariate models. However, some of the models have weaknesses that may affect the outcome. For example, using binary response models like the linear probability model may lead to a challenge where the disturbance terms become deterministic and heteroskedastic hence the predicted probability could be over 1 or below 0 for extreme values of dependent variables (Breen *et al*., 2018). On the other hand, use of the univariate model will not allow measurement of the potential correlation between unobserved disturbances and the relationship between choices (Fountas & Anastasopoulos, 2018). To overcome these challenges a multivariate Probit model was employed because it allows simultaneously choosing multiple responses. Hence the Multivariate Probit model (MVP) was suitable for this analysis (Becker *et al*., 2017). The MVP is a binary response regression model used to simultaneously estimate the observed and unobserved influence on dependent variables by several independent variables, permitting error terms to correlate freely (Oduniyi & Tekana, 2021). The general equation for the MVP is specified as follows;

$$Y^*_{im} = x_{im}\beta_m + \varepsilon_m \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 8$$

$Y^*_{im}$ =1 if $Y^*_{im}$>0, 0 otherwise, m = 1, ……, M

where $Y^*_m(m = 1, \ldots, K)$ represent the unobserved latent variable of agrometeorological information pathways adopted by the $i^{th}$ smallholder sorghum farmer ($i$ = 1, …, n). Equation (9) $X_{im}$ is a vector of covariates, including specific attributes of the pathways and individual farmer and farm characteristics, β is vector of unknown regression coefficients and $\varepsilon_m$ is residual error.

Therefore, K represents the number of agrometeorological information pathways. $\beta_m$ is a k × 1 vector of unknown parameters to be estimated $\varepsilon_m$, for all m = 1, …, n are the error terms distributed as multivariate normal, each with a mean of zero, and variance-covariance matrix which has values 1 on the leading diagonal and correlations (Piya *et al.*, 2013). The system of equations describing the binary equations is as follows;

$$\begin{pmatrix} and Y^*_1 = X_1\beta_1 + \varepsilon_1 \; Y_1 = 1 \; if \; Y^*_1 \succ 0, \; Y_1 = 0 \; otherwise \\ and Y^*_2 = X_2\beta_2 + \varepsilon_2 \; Y_{2`} = 1 \; if \; Y^*_2 \succ 0, \; Y_2 = 0 \; otherwise \\ and. \\ and. \\ and Y^*_n = X_n\beta_n + \varepsilon_n \; Y_{n`} = 1 \; if \; Y^*_n \succ 0, \; Y_n = 0 \; otherwise \end{pmatrix} \ldots\ldots\ldots 9$$

This system of equations is jointly estimated using maximum likelihood method. The following equation calculated the marginal effects of independent variables on the propensity to choose different agrometeorological information pathways (Ogunpaimo *et al.*, 2020).

$$\frac{\partial P_i}{\partial x_i} = \phi(x'\beta)\beta_i, i = 1,2,3, \ \ldots \ \ldots \ , \ n \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 10$$

where $P_i$ is the likelihood of event *i* which increases choice of each agrometeorological information pathway option, and $\varphi(.)$ is the standard univariate normal density distribution function.

Factors influencing the choice of a particular agrometeorological information pathway were used as independent variables informed by past studies (Antwi-Agyei *et al.*, 2021; Kirui *et al.*, 2014; Murage *et al.*, 2011; Nyasimi *et al.*, 2016; Ouédraogo *et al.*, 2019) and were summarised as presented in Appendix 1 with the expected relationship.

$$Y^*_n = \beta_0 + \beta_1\, age + \beta_2\, educ + \beta_3\, gender + \beta_4\, hhsize + \beta_5\, expe + \beta_6\, income + \beta_7\, farmsize + \beta_8\, ownfarm + \beta_9\, mktdst + \beta_{10}\, credit + \beta_{11}\, extension + \beta_{12}\, farmgroup + \beta_{13}\, topography + \beta_{14}\, infoaccess + \beta_{15}\, agromettrust \ldots\ldots\ldots\ldots \quad 11$$

**Objective 2: Empirical modelling for factors influencing access to agrometeorological information among sorghum farmers in Busia County, Kenya**

Access to agrometeorological information by smallholder sorghum farmers is a discrete choice form. Specifically, one (1) denotes smallholder sorghum farmers who accessed agrometeorological information, and zero (0) denotes otherwise. The common models used for estimating such parameters include the linear probability model (LPM), Logit and Probit models (Maddala & Rao, 2005). The LPM could have been the simplest to use but the functional form is generally not correctly specified and can lead to biased estimates of some parameters (Deke, 2014). This leaves the choice between logit and Probit, which are widely used in practice. According to Johnston and DiNardo (1997), the difference between the logit and Probit models is rarely large to discriminate between them because both seem to produce a similar result. Eventually, estimates from both models produce similar results and using one or the other is a matter of habit or choice. However, the Probit model is less robust hence less accommodating outliers compared to the Logit model. Therefore, the binary Logit model was used for this objective since the logit model is easier to interpret. The binary Logit model guarantees that the estimated probabilities lie in the 0–1 range and that it is nonlinearly related to the explanatory variables (Gujarati & Porter, 1995). The binary logit model has been widely adopted since the 1960s because it has analytical advantages in dealing with discrete binary outcomes (Long & Mustillo, 2021). The general form of a binary logit model is as follows (Greene & Hensher, 2010).

$$P_i(Y_i = 1)\frac{e^{Z_i}}{1+e^{Z_i}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 12$$

where $P_i$ is the probability that the $i^{th}$ household accessed agrometeorological information and $Z_i$ is the linear function of the independent variables (socioeconomic, institutional, and climate-related factors). The linear function can be expressed as follows

$$Z_i = \beta_0 + \beta_i \sum_{i=1}^{n} X_i + U_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 13$$

where $\beta_0$ is the constant term, $\beta_i$ is coefficients of the independent variables, $X_i$ independent variables, and $U_i$ is the error term. The $\beta_i$ indicates how access to agrometeorological information is affected as a result of changes in independent variables. To compute the odds for access to agrometeorological information, we divide the odds of someone who accessed agrometeorological information $P_i$ by the odds for someone who has not accessed agrometeorological information $(1 - P_i)$.

smoked for 14 years.

The marginal effect (ME) coefficient is a major tool for analyzing the binary logit model. Marginal effect coefficients are determined as follows (Greene, 2003)

$$ME = \frac{\partial \Lambda(X'\beta)}{\partial X} = \Lambda(X'\beta)[1 - \Lambda(X'\beta)]\beta \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 14$$

where; X is the matrix of the independent variables in the logit model (socioeconomic, institutional, and climate-related factors) and β is a matrix of parameters in the logit model.

In correspondence with previous studies on access to agrometeorological information conducted by Kirui *et al.* 2012, Oyekale (2012, 2015), and Wekesa 2017 the socioeconomic, institutional, and climate-related factors influencing access to agrometeorological information are indicated below.

$$Access = \beta_0 + \beta_1\, age + \beta_3\, educ + \beta_4\, gender + \beta_5\, occup + \beta_6\, hhsize + \beta_7\, exp + \beta_8\, income + \beta_9\, landsize + \beta_{10}\, farmsize + \beta_{11}\, mktdst + \beta_{12}\, credit + \beta_{13}\, extension + \beta_{14}\, training + \beta_{15}\, group + \beta_{16}\, insurance + \beta_{17}\, radio + \beta_{18}\, tv + \beta_{19}\, phone + \beta_{20}\, internet + \beta_{20}\, TesoN + \beta_{21}\, Samia + \beta_{22}\, Matayos \ldots\ldots\ldots\ldots\ldots\ldots 15$$

**Table 3. 2** Definition of working variables

| Variables | Measurement | Expected sign |
|---|---|---|
| **Dependent variables** | | |
| Access to agrometeorological information | 1 for access agrometeorological information, 0 otherwise | |
| **Independent variables** | | |
| Sub-County | Sub county of residence (Teso South being base category) | ± |
| Household size | Size of the household (Number of people) | ± |
| Farming experience | Period the respondent has been farming (Years) | ± |
| Group | Membership to a group (1 for yes, 0 otherwise) | ± |
| Extension visits | Frequency of extension visits (Number) | ± |
| Credit access | Access to credit facilities (1 for yes, 0 otherwise) | ± |
| Market distance | Distance to the market for crop produce (Kilometers) | ± |
| Gender | Gender of the key decision-maker (1 for male, 0 otherwise) | ± |
| Age | Age of the key decision-maker (Years) | ± |
| Education | Education level of the key decision maker (School Years) | ± |
| Income | Major income of the key decision-maker (Kenya Shillings) | ± |
| Farm land | Proportion of land under farming (Acres) | ± |
| Income for farming | Proportion of income allocated to farming (Shillings) | ± |
| Radio | Radio ownership (1 for yes, 0 otherwise) | ± |
| TV ownership | TV ownership (1 for yes, 0 otherwise) | ± |
| Internet | Access to internet services (1 for yes, 0 otherwise) | ± |
| Phone | Mobile phone ownership (1 for yes, 0 otherwise) | ± |

**Objective 3: Econometric estimation of factors influencing the uptake of climate-smart agricultural practices**

In this study, the adoption of (CSA) practices was quantified by counting the number of CSA techniques utilized by smallholder sorghum farmers over the past year to mitigate climate-related shocks. To analyze the factors influencing the uptake of these practices, the study employed a Poisson regression model, which is suitable for count data outcomes. Following Cameron and Trivedi (2013), the observed number of CSA practices by the smallholder sorghum farmers, $y_i$ , conditioned by a vector of covariates $X_i$, is a count variable that can be specified as follows:

$$f(Y = y_i) = \Pr(Y = y_i) = \frac{e^{-\lambda_i}\lambda_i^{y_i}}{y!} = \qquad y_i = 0,1,2 \ldots \ldots n \ldots \ldots \ldots \ldots \ldots \ldots \ldots 16$$

where, parameter $\mu_i$ is the conditional mean number of events for each explanatory variable. The parameter $\mu_i$ is given by

$$\mu_i = EXP(x_i'\beta) \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots .17$$

where, $\beta$ is a $(k+1)$ x 1 parameter vector with the $\beta_0$ parameter being the coefficient for the intercept and $\beta_{1,}\ \beta_{2,}\ \beta_{3,} \ldots, \beta_k$ are coefficients associated with $k$ regressors.

The Poisson model was selected to estimate the relationship between the adoption of Climate-Smart Agriculture (CSA) practices and the independent variables for smallholder sorghum farmers. This model is suitable for count data where the variance is assumed to be equal to the mean, as outlined by Cameron and Trivedi (2013). If the data distribution did not meet this assumption, alternative models could have been considered, including the over-dispersed Poisson, negative binomial, or two-stage (hurdle) and zero-inflated models. These alternatives account for scenarios where the variance exceeds the mean, thus addressing potential over-dispersion in the data. The core assumption of the Poisson model is that the mean of the count outcome variable is equal to its variance. This relationship can be expressed as:

$$V(y_i/Xi) = E\left(\frac{y_i}{x_i}\right) = \mu_i \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots ..18$$

where $y_i$ is the uptake of CSA practices by the smallholder sorghum farmers (non-negative integer), $X_i$ is a vector of the uptake of CSA practices by the smallholder sorghum farmers, and $\mu_i$ is the conditional mean of the uptake of CSA practices.

The adoption of Climate-Smart Agriculture (CSA) practices by smallholder sorghum farmers is influenced by individual preferences and a range of other factors, leading to variability in how often these practices are implemented. The reasons behind adopting CSA practices and the extent to which they are applied can be complex, as they are influenced by different types of climatic shocks. It is challenging to pinpoint why certain factors might affect the adoption of CSA practices in one context but not in another. Consequently, the study assumes that the explanatory variables used in the Poisson model to analyze the uptake of CSA practices are consistent across different contexts.

The Poisson model for assessing the determinants of CSA practice uptake includes variables aligned with findings from previous research. These studies have investigated various factors affecting CSA adoption and uptake, providing a basis for selecting relevant variables for this model (Antwi-Agyei *et al*., 2021; Gbegeh & Akubuilo, 2013; Gbetibouo, 2009; Nuani *et al*., 2022; Teklewold *et al*., 2019).

**Objective 4: Econometric modeling of effect of adaptation to climate variability, agrometeorological information, socioeconomic and institutional factors on agricultural productivity among sorghum farmers in Busia County.**

The study utilized an endogenous switching regression (ESR) model to examine how climate variability adaptation impacts agricultural productivity. This model, an extension of Heckman's selection correction approach, was introduced by Lee (1982) to tackle selection bias arising from unobserved heterogeneity. Such bias can occur when unobserved factors influence the adaptation decisions of smallholder sorghum farmers in Busia County, potentially distorting the analysis of their adaptation strategies. The ESR model helps correct for this bias, providing a more accurate assessment of how adaptation practices affect productivity.

An Endogenous Switching Regression (ESR) model operates in two stages. In the first stage, a Probit model is employed to analyze the adoption decision. This stage focuses on identifying the socioeconomic factors that influence the decision to adapt to climate variability and how these factors affect agricultural productivity (Biru *et al*., 2020). The selection model estimated in this stage is specified as follows:

$$Z_i^* = a + \gamma Q_i + \varepsilon_i \quad \text{……………………………………………………………………….19}$$

where $Z_i^*$ was a binary takes the value 1 if the smallholder farmer adapted to climate variability and 0 otherwise; $a$ was an intercept; $Q_i$ was a vector of explanatory variables influencing adaptation to climate variability; $\gamma$ was a vector of coefficient, and $\varepsilon_i$ was the disturbance term with constant variance and zero mean. The error term comprises measurement error and factors not observed by the researcher but known to the farmer.

In the second stage of the ESR model, a full information maximum likelihood (FIML) model was used to account for potential selection bias. Separate regression equations are used to model sorghum productivity conditional on specified criterion functions (Ankrah Twumasi *et al.*, 2020). The binary outcomes (increased sorghum productivity) conditional on adapting to climate variability were represented as switching regimes as follows:

Regime 1: $Y_{1i} = X_{1i}\beta_1 + \sigma_{1\varepsilon}\lambda_{1i} + u_{1i}$ if $A_i = 1$ for adapters to climate variability…………….….20

Regime 2: $Y_{2i} = X_{2i}\beta_2 + \sigma_{2\varepsilon}\lambda_{2i} + u_{2i}$ if $A_i = 0$ for non-adopters to climate variability…………21

where $Y_i$ represented the outcome variable (sorghum productivity) for a farmer $i$ for each regime (1 = adopter to climate variability and 0=non-adopter); $X_i$ was a vector of explanatory variables that affect agricultural productivity. The variables in vectors $X$ in equations 20 and 21 may overlap with $Q$ in equation (19). However, the approach requires that at least one variable in $Q$ that does not appear in $X$. $\beta$ and $\sigma$ were parameters to be estimated, $u_{1i}$ and $u_{2i}$ were independently and identically distributed error terms of the agricultural productivity estimation equation. This indicates that the ordinary least squares (OLS) estimates of $\beta_1$ and $\beta_2$ will suffer from the sample selection criterion have non–zero expected values (Alene & Manyong, 2007). The non-zero covariance between the error terms of the selection equation and the outcome equation showed the existence of selection bias, and the null hypothesis of the selection bias would be rejected. The Inverse Mills Ratio (IMR) of adaptation computed from the selection Equation 19 is included in Equations 20 and 21 as a remedy for selection bias in the two-step estimation procedure (i.e., endogenous switching regression) as shown in Equation 22

$$\lambda_{1i} = \frac{\Phi(Z_i\alpha)}{\Phi(Z_i\alpha)} and \lambda_{2i} = \frac{\Phi(Z_i\alpha)}{1-\Phi(Z_i\alpha)}$$ ……………………………………………………………….22

The three error terms $\varepsilon_i$, $u_{1i}$ and $u_{2i}$ are assumed to follow a tri-variate normal distribution with zero mean factor and non-singular covariance matrix as shown in Equation 23

$$Cov(\varepsilon_i, u_{1i}, u_{2i}) = \begin{pmatrix} \sigma_1^2 & \sigma_1\sigma_2 & \rho_{1e}\sigma_1 \\ \sigma_1\sigma_2 & \sigma_2^2 & \rho_{2e}\sigma_1 \\ \rho_{1e}\sigma_1 & \rho_{2e}\sigma_2 & \sigma_\varepsilon^2 \end{pmatrix} \quad \text{.........................................................23}$$

where $\rho_{1e}$ and $\rho_{2e}$ were correlation coefficients between $u_{1i}$ and $\varepsilon_i$, and between $u_{2i}$ and $\varepsilon_i$, respectively. If either $\rho_{1e}$ and $\rho_{2e}$ was significantly different from zero, the presence of selection bias would be confirmed. If $\rho > 0$, then there was negative selection bias, signifying that farmers with below-average sorghum productivity were more likely to adapt climate variability. If $\rho < 0$, a positive selection bias would indicate that farmers above average sorghum productivity are more likely to adapt to climate variability. In addressing the endogeneity problem within the selection model, the study used two instrumental variables: the frequency with which respondents received agrometeorological information and their level of trust in this information. These variables were chosen because they impacted the adaptation decisions of sorghum farmers with regard to climate variability, but did not have a direct effect on sorghum productivity. The frequency of receiving agrometeorological information was selected due to the various sources available to farmers, which varied based on their access. Additionally, trust in the reliability and consistency of this information was considered crucial, as it could influence the farmers' willingness to adapt to climate variability. The primary objective of the study was to estimate the average treatment effects, specifically the change in sorghum productivity attributable to adaptation to climate variability. This effect was quantified as the difference in productivity outcomes between those who adopted adaptation strategies and those who did not. The average treatment effect was represented by $Y_1$ (sorghum productivity) as shown in the equations. The equation for the expected conditional and average treatment effects for the adopters and non-adopters to climate variability groups were given as:

The equation for the farmers practicing sorghum production.

$$E\left[Y_{1i} / X.A_i = 1\right] = \alpha_1 + X_{1i}\beta_1 + \rho_{1i}\sigma_{1\varepsilon}\lambda_{1i} \quad \text{..........................................................24}$$

The equation for adapters, they decided not to adapt to climate variability:

$$E\left[Y_{2i} / X.A_i = 1\right] = \alpha_2 + X_{2i}\beta_2 + \rho_{2i}\sigma_{2\varepsilon}\lambda_{2i} \quad \text{..........................................................25}$$

The equation for non-adopters, they decided to practice sorghum production:

$$E\left[Y_{1i} / X, A_i = 0\right] = \alpha_1 + X_{1i}\beta_1 + \rho_{1i}\sigma_{1\varepsilon}\lambda_{1i} \quad \text{......26}$$

The equation for the non-adopters, which did not adapt to climate variability:

$$E\left[Y_{2i} / X, A_i = 0\right] = \alpha_2 + X_{2i}\beta_2 + \rho_{2i}\sigma_{2\varepsilon}\lambda_{2i} \quad \text{......27}$$

The heterogeneity effects using the expected outcomes are calculated as described in Equations 24 to 27. The base heterogeneity for adopters to climate variability was calculated as the difference between equations 24 and 26. In contrast, the base heterogeneity of the non-adopters was calculated as the difference between equations 25 and 27. Finally, we estimated the transitional heterogeneity (ATT-ATU) to understand whether the impact of sorghum productivity was larger or smaller for farmers adapted to climate variability. Thus, the estimated change in the level of sorghum productivity for farmers who adapted to climate variability (the average treatment effect of the treated households or ATT was given as

$$ATT = (a) - (b)$$

$$= E\left[Y_{1i} / X, A_i = 1\right] - E\left[Y_{2i} / X, A_i = 1\right]$$

$$= X_{1i}(\beta_1 - \beta_2) + \lambda_{1i}(\sigma_{1\varepsilon} - \sigma_{2\varepsilon}) \quad \text{......28}$$

**Table 3. 3** Conditional expectations, treatment, and heterogeneous effect

| Sub-samples | Decision stage | | Treatment effects |
|---|---|---|---|
| | To adopt | Not to adopt | |
| Adopters | (a) $E\left[Y_{1i} / X, A_i = 1\right]$ | (b) $E\left[Y_{2i} / X, A_i = 1\right]$ | ATT |
| Non- adopters | (c) $E\left[Y_{1i} / X, A_i = 0\right]$ | (d) $E\left[Y_{2i} / X, A_i = 0\right]$ | ATU |
| Heterogeneous effects | $BH_1$ | $BH_2$ | TH |

NB: (a) and (d) are observed outcomes, while (b) and (c) are the hypothetical unobserved outcomes (expected situations). $A_i = 1$ if farmers adopted to climate variability; $A_i = 0$ if farmers did not adapt to climate variability. ATT and ATU denotes average treatment effect on the treated and untreated. $BH_1$ is the effect of base heterogeneity for farmers who adapted to climate variability $(A = 1)$ and $BH_2$ for those who did not adopt $(A = 0)$. TH: Transitional heterogeneity = ATT-ATU.

Similarly, we estimated the expected change on non-adopter farmers as the average treatment effect on the untreated farmers (ATU) given as:

$$ATT = (c) - (d)$$

$$= E\left[Y_{1i} / X, A_i = 0\right] - E\left[Y_{2i} / X, A_i = 0\right]$$

$$= X_{2i}(\beta_1 - \beta_2) + \lambda_{2i}(\sigma_{1\varepsilon} - \sigma_{2\varepsilon}) \qquad \text{......29}$$

# CHAPTER FOUR
# RESULTS AND DISCUSSION

## 4.1 Descriptive Statistics

### 4.1.1 Continuous Variables

Results in Table 4.1 indicate that the average age of the respondents was 48 years. This indicates that sorghum farmers in the study area were fairly old. This finding corroborates previous studies in Western Kenya (Musafiri *et al.*, 2022; Wetende *et al.*, 2018), who found that the sampled households were still in the active age bracket. The study further revealed that the average years of schooling was nine years, implying that most respondents had at least primary school education level. These findings agreed with Mathiu *et al.* 2021 who reported an average of schooling of 9.98 years in a study conducted in Tigania West Meru, Kenya. This result implies that farmers are knowledgeable enough and understand the significance of climate variability and the importance of accessing agrometeorological information. The respondents have at least two decades (21 years) of farming experience meaning that majority of the sorghum farmers were aware of climate change and variability and its effects. The average distance from the farm to the market where decision-makers buy and sell inputs and farm produce respectively was 3 kilometres (km). Farmers received approximately 2 extension visits in a year for farming, production, value addition and marketing advice of agricultural commodities. Farming households have 7 family members, while most farmers had received agrometeorological information 4 times within the year.

**Table 4. 1** Description of variables and descriptive statistics

| Continuous variables | Variable description and their measurements | Mean |
|---|---|---|
| Age | Age of the decision-maker [a] in years | 48.07 |
| Distance | Distance from home to the market (in km [b]) | 2.53 |
| Education | Years of education of the respondent | 8.25 |
| Farming Experience | Respondent's farming experience in years | 21.36 |
| Extension visits | Frequency of extension visits in a year | 1.90 |
| Household size | Number of household members | 6.56 |
| Training | Training counts attended in the last 12 months | 2.15 |
| Agrometinfor | Agrometeorological information count in a year | 3.82 |

[a] Decision-maker is the household member responsible for making farming decisions.

[b] km = distance in kilometres

### 4.1.2 Binary Variables

The distribution of respondents by their socioeconomic and institutional characteristics table 4.2 revealed that 63% of the respondents were female. The result implies that women carried out most farming activities compared to males. Farming was the main economic activity for 92% of the farmers in the study area with majority allocating more than 68% of their land to farming, while spending approximately 15% of their income to finance farming activities and 58% receiving credit facilities to finance their agricultural production. Majority of the respondents had been exposed to climate change shocks such as droughts, floods and erratic rainfall. This affirms the statement of Mogaka *et al.* (2021) that most farmers in SSA have been affected by climate change. A relatively larger percentage of farmers (72%) belonged to farmers group showing the importance of social capital in accessing information.

**Table 4. 2** Description of Binary variables and descriptive statistics

| Variable | Variable description and their measurements | Percent |
|---|---|---|
| Gender | % of male decision-makers | 37.12 |
| Income | % of respondents with farming as the main income activity | 91.02 |
| Farming land | Proportion of land under farming (Acres) | 0.68 |
| Prop income farm | Proportion of income allocated to farming | 0.15 |
| Access credit | % of respondents with access to credit facilities | 57.68 |
| Exposed climate shocks | % of respondents exposed to climate shocks | 90.31 |
| Group membership | % of respondents who are members of farmers group | 71.39 |
| Mobile phone | % of respondents who own mobile phone | 78.96 |
| Internet services | % of respondents who access internet services | 43.26 |
| Radio | % of respondents who own radio | 58.63 |
| Television | % of respondents who own television | 40.43 |
| Language comprehensible | % of respondents who comprehended language used in information dissemination | 74.94 |
| Agrometinfor trust | % of respondents who trust agrometeorological information services | 37.83 |

[a] Decision-maker is the household member responsible for making farming decisions.

[b] km = distance in kilometres

It was also revealed that the majority (79%) of the respondent owned a mobile phone. The fact that most of the farmers in the study area owned mobile phones reflects how farmers understand how important these devices are in accessing information including agrometeorological related. The findings agree with those of Krell *et al.* (2021), who reported that 98% of the respondents in central Kenya owned mobile phones. The study further revealed that mobile phones have transformative potential to furnish farmers in the rural setting with important agrometeorological information. Access to internet facilities was relatively low as only 43% of the sorghum farmers were able to access. This result reveals that very few farmers use internet services to access agrometeorological information. This can be attributed to the cost of connectivity and poor internet infrastructure in rural areas. This could also be attributed to lack of smartphones, advanced age and relatively low education level of the respondents. Radio ownership among the respondents was 59%. The findings corroborate with Keinembabazi (2022), who revealed that most farmers (56%) owned radios since most agrometeorological information was disseminated through radio stations. Respondents who owned television were about 40%. The result implies that very few farmers can access agrometeorological information through television. This result can be attributed to the cost of owning one and the lack of access to electricity that is important in operating a television. Regarding the agrometeorological information received by the farmers through different pathways, 38% of the farming households trusted the agrometeorological information services this may be due to past experiences where the information received may not have been reliable. On the other hand, 75% 0f the decision-makers believed the language used in disseminating climate variability information to be comprehensible and therefore understood it.

### 4.1.3 Information pathways choice

In general, the choice for radio information pathway was the highest at 74% followed by TV (23%) while the use of extension officers as sources of information pathway and mobile internet was the least preferred at approximately 18% and 15% respectively. The results show that the main mode of information dissemination that reached majority of the farmers among respondents was radio and TV. This implies dissemination of information through media particularly the local vernacular radio stations which have a wider audience among small scale farmers could increase access. Radio is argued to be the cheapest source of information dissemination and convenient among small-scale farmers as they need less power to function and are flexible to be moved from one place to the other. TV use came second in order of preference since most rural farms who accessed it argued that it helps in visualising agrometeorological information, improving their judgement. When adopting a given CSA technique, the diffusion of innovation theory stresses the power of seeing. For instance, when explaining the steps of integrated farming techniques to farmers, farmers with TV were observed to adopt more CSA practices than radio sources. However, few small farmers have access to TV due to various challenges ranging from affordability to inadequate power sources for powering the TV (solar panels or electricity).

The results in Figure 4.1 reveal information dissemination through extension services and mobile internet is not fully utilized and interventions are needed to enhance their adoption as sources of information dissemination pathway. This could be attributed to less exposure by farmers to embracing these choices. Moreover, some extension services are offered at a fee from private consultants and other non-governmental organisations, making them less preferred by small-scale farmers. Even though the use of extension services is less preferred due to several challenges, farmers who used the pathway as a source of information dissemination argued that it offers an excellent opportunity to converse with the experts with instant feedback in most cases. In a simple context, the use of extension services has a forward and backward communication between farmers and the extension officers who, for instance, visit the farmers on sight and can address the physical and actual challenges facing farmers. However, this method is commonly used by large-scale and progressive farmers who have invested heavily in their firms and seek extension services for enhanced agricultural productivity. This reveals the importance of using extension services as a source of information dissemination pathways on climate change effects and its vulnerabilities. Therefore, it should be promoted for adoption for modern farming practices. Therefore, extension officers need to be well trained on climate change adaptation techniques relevant to the needs of farmers and applicable in the producers' specific environment. Similarly, Omer & Hassen (2020) revealed that over 42% of the farmers relied on radio as an information dissemination pathway but to a limited extent through mobile phones, internet, extension services and barazas.

The use of mobile phones has increasingly gained recognition and importance in disseminating agrometeorological information in SSA. Additionally, in the past few years, agrometeorological information dissemination infrastructure in relation to radio and television coverage and cell phone network and ownership of these information source assets have been on the rise in SSA. The number of mobile phone subscribers in SSA has been steadily growing, indicating a solid importance when ensuring that climate information reaches a wider area of farming households. However, majority of rural farming households prefer using other alternative information dissemination pathways such as radio, TV and directly from their peer than mobile phones. A discussion with some of the smallholder farmers reveals the reason for the low use of the mobile phone was that it requires the purchase of data bundles or airtime to make phone calls and send USSD text messages to receive farming information. The challenges above made mobile phone use for information dissemination unaffordable among smallholder farmers, further discouraging their use as information sources.

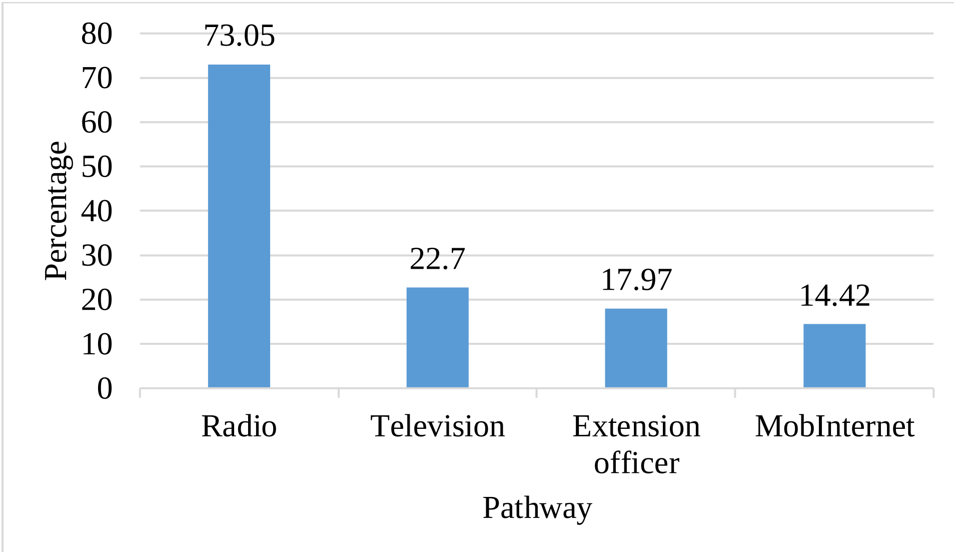


**Figure 4. 1** Descriptive statistics on the choice of information pathways

### 4.1.4 Adoption of CSA practices

The average number of Climate-Smart Agriculture (CSA) practices adopted by sorghum farmers over the past year was two. The maximum number of CSA practices adopted annually by smallholder sorghum farmers was 13, whereas the minimum was zero. This variation in adoption levels likely stems from factors such as a lack of awareness and affordability of these practices, consistent with findings from previous studies. Kalele *et al.* (2021).

## 4.2. Factors influencing farmers' choice of dissemination pathways for agrometeorological information among smallholder sorghum farmers in Busia County.

To determine the factors influencing farmers' choice of agrometeorological information pathways among smallholder sorghum farmers, a Multivariate Probit was analysed using the maximum likelihood method. The wald test value (261.07) indicated that the regression coefficients in all equations were not jointly equal to zero, and the null hypothesis was rejected, implying that the data fit analysis using the MVP model. Moreover, the likelihood ratio test value (35.812) of the null hypothesis of the covariance matrix across the 4 equations was rejected, implying a correlation between the error terms of the information pathways equations. This affirms that the choice for different combinations of information dissemination pathways was mutually dependent.

To ascertain the feasibility and reliability of the MVP model in analysing the relationship between the use of different information dissemination pathways combinations, error terms between the binary choice equations for each of the selected pathway choices were estimated (Table 4.3). Of the six pairs, one pair was negative and significant, while three were positive and significant. The remaining two pairs were positive and insignificant. Estimated correlation coefficients between pairs of information dissemination pathways were significantly different from zero, implying a strong relationship among the analysed pathways. The significant negative coefficients between extension officer information pathways and radio information pathways (-0.239) indicated that these information pathways are used as substitutes. In the absence of extension services, farmers could still use radio to access agrometeorological information. However, majority of smallholder farmers prefer using radio over extension services with an argument that it is more cost-effective than inadequate extension services. Currently, many radio programmes frequently air new farming technologies to be adopted by farmers. The farmer needs to have an explicit schedule on when the program will be on air for them to benefit. This could be hard for some farmers who might be engaged when the programme goes live on air. On the other hand, some extension services can be inaccessible to farmers in some areas on remote areas with impassable roads, therefore limiting their potential to help farmers. The highlighted reasons justify why the use of radio and extension services are treated as substitutes.

The significant positive coefficients between TV and Radio (0.185), mobile internet and T.V. (0.286) and mobile internet and extension officer (0.361) implied that the information pathways were complements. For instance, radio provides audio agrometeorological information dissemination services to farmers and is very useful when providing general climate change and farming technology information. However, when complicated farming technology needs to be taught to farmers, the use of radio becomes limited. On the other hand, television sets allow farmers to listen (audio) and watch (visual) the actual farming information being passed to farmers. New generation television sets can record live events such as farmer training which air on Tv for future watch. This allows farmers to record the sessions and play them during their free time, complementing radio's shortcomings as information dissemination pathways. The highlighted findings reveal that the MVP model was applicable in this study

**Table 4. 3** Binary correlation coefficients for multivariate Probit regression equations

| | Radio | Television | Extension officer |
|---|---|---|---|
| Television | 0.185* | | |
| Extension officer | -0.239*** | 0.140 | |
| Mobile Internet | 0.145 | 0.286*** | 0.361*** |

***, * = significant at 1% and 10%, respectively.

Out of the 19 explanatory variables, 9 variables; education, gender, proportion of income allocated to farming, access to credit facilities, frequency of extension visits, training counts, access to internet services, radio ownership, and use of comprehensible language had positive, or negative, significant, influences on choice for agrometeorological information dissemination pathways. The remaining 10 covariates did not influence farmers' choice of information dissemination pathway combinations.

Higher education levels positively influenced decision-makers' access of agrometeorological information through television and mobile pathways. There was significant relationship between education level and use of television and mobile as information pathways at 1% and 5% significance level respectively. Education empowers farmers with the necessary skills and knowledge to acquire, relate, and adopt recommended and advanced farming technologies. Onubuogu and Esiobu (2014) reported similar findings, noting that educated farmers were more knowledgeable about climate change adaptation strategies, which influenced their choice of adaptation options. Educated farmers are knowledgeable enough to understand the significance of accessing agrometeorological information. High literacy levels are associated with formal employment and a higher exposure to more information and ability to process and make good use of the acquired knowledge. Some of these literate farmers have the financial ability to purchase television sets and smartphones which increases information accessibility through these pathways. Additionally, most literate farmers prefer setting aside some of their time to learn more about new and advanced farming technologies, which are aired on multiple Tv stations in the local, regional and global channels. Moreover, specific Tv channels exclusively air farming technological practices in languages convenient for these farmers to comprehend. Moreover, high literacy levels among farming households create curiosity and hunger for information and learning new things through different avenues and influence farmers' attitudes and decisions, leading them to become more open, rational and capable of evaluating the benefits of different pathways therefore, they are likely to access and utilise advanced agrometeorological information through multiple reliable and efficient pathways (Duffy, 2017). The television pathway provides interesting audio-visual programs concerning new and important farming strategies, while mobile internet offers flexible and easy accessibility to agrometeorological information at farmers' convenience and is cost-effective (Muriithi Lydia *et al.*, 2021). Relaying agrometeorological information on appropriate farming techniques through readily available information likely enhances agricultural technologies' uptake.

Male farming decision-makers had a greater chance of accessing agrometeorological information through radio, television and mobile internet pathways. The relationship between gender and use of radio, television and mobile internet pathways was significant at 5% significance level. Male and female decision-makers perceive and experience climate change differently due to their distinct gender roles, responsibilities, status, and identities shaped by societal norms. Traditional and social barriers make it difficult for women to access and control resources leading to limited access to information. Men and women likely have varied perceptions of adopting farming strategies because of differences in accessing productive resources and agricultural information services. Moreover, social norms complicate womens' ability to adopt new farming technologies due to different levels of accessing farming information and other resources like land due to lack of property rights. In Kenya, for example, women are prevented by many cultures and taboos from owning property or making an independent farming decision (Waaswa *et al.*, 2021). Men decide what to farm, or women, in consultation with their husbands or male family members, make farming decisions. Similarly, Lamontagne-Godwin *et al.* (2018) found that male decision-makers were more likely to look for farming information from multiple pathways than women due to convenience, accessibility, and patriarchal socio-cultural norms. This is further echoed by Abaje *et al*. (2014) who observed that, in contrast to men, women face restricted access to information, land, and other resources due to traditional social barriers, resulting in a lower likelihood of adopting response measures.

Farmers who allocated a higher proportion of their income to farming accessed most of their agrometeorological information through radio pathway. There was a significant relationship between higher proportion of income allocated to farming and use of radio as an information pathway at 1% significance level. Farming households allocate a larger percentage of their income to agriculture as an investment with expected returns. These households probably have a high demand for agrometeorological information aiming to achieve optimum production; therefore, choose a well packaged, accessible and reliable information dissemination pathway that will assist them in attaining their goals. Additionally, radio provides agricultural programs in local vernacular hence the most popular channel among farmers. This is in line with the findings of Adolwa *et al.* (2018) who noted that mass media pathways such as radio are highly preferred since agrometeorological knowledge supplies can reach a wider audience (farmers) over long distances. Moreover, Lwoga (2010) found that majority of small-scale farmers rely on radio to receive agro-based information due to its high-level utility at all stages of farm production.

Access to credit facilities influenced access of agrometeorological information through radio and TV pathways by small scale farmers. Access to credit gives farmers a chance to invest more in farming which increases their need to get important weather information that will enhance their farming activities. More financial resources available to farmers influences the utilization of all the available sources of information on changing climatic conditions which are easily accessible and understandable, hence changing their management practices in response to safeguard their investments. Small-scale farmers are most vulnerable due to factors constraining them from adapting to climate change; lack of finances is one of the constraints (von Loeper *et al.*, 2016). Therefore, access to credit facilities gives farming households an incentive to seek information concerning adaptation to climate variability using multiple pathways; all require finances to implement, which agrees with (Ncoyini *et al.*, 2022).

Households which received more extension visits within a year were more likely to choose extension officers as sources of information pathways. There was a significant relationship between number of extension visits and choice of extension officers as an information pathway at 10% significance level. Farmers with extensive extension contacts are more likely to stay informed about shifting climatic conditions, as extension agents provide them with up-to-date agricultural information and technologies to mitigate the adverse effects of climate change Krishna *et al.* (2019) found out that agricultural extension services are very important in enhancing human capital by acquiring relevant farming information from a wider knowledge base, especially rural livelihoods. Frequent social interaction between farmers and extension officers enables a regular flow of information from extension personnel to farmers, which is crucial for the diffusion of new farming technologies in the most effective way. Moreover, face-to-face interaction between farmers and extension officers provide feedback through question and answer session; therefore, extension officers are more likely to be chosen as an alternative agrometeorological information pathway (Cook *et al.*, 2021).

Decision makers who had received a higher number of agrometeorological trainings were less likely to access agrometeorological information through radio pathway but more likely to receive information through extension officers at 1% significance level. Farmers who have received much training on agrometeorological information tend to trust and use the knowledge they get from the trainings than look for information from other sources. Furthermore, most of the trainings are facilitated by the extension officers or facilitators who are brought by the officers hence the increased reliance on information from the extension officers. The use of radio to disseminate climate information through training to farmers is not very effective as it mostly relies on one-way information flow without getting farmers' feedback (Gwenzi *et al.*, 2020), implying a lack of full participatory approach. Contrary, Cook *et al.* (2021) revealed that regular training conducted by extension officers creates synergy between farmers and the information suppliers. A discussion with the respondents revealed that small-scale farmers could enrich the existing climate information through observation, practice, and experience.

Farmers who had access to internet were more likely to use radio as a choice of information dissemination pathway at 1% significance level. Farmers who are able to access to internet in the rural areas are more likely to afford radio and some radio stations can be accessed online which is enhanced by internet access. This makes it easy to complement the information received from the two pathways. Sometimes internet bundles become expensive and farmers may resort to radio as the next best alternative. Moreover, farmers may want to clarify what they see on the internet by listening to radio. The use of the internet as a pathway for agrometeorological information enhances interactions between farmers and information providers (Ofoegbu & New, 2022). Additionally, it provides a wide information base that benefits farmers concerning all aspects of climate variability production challenges and the necessary solutions. However, internet services are the least accessible to small scale farmers in rural areas due to poor connectivity, implying that internet pathways for supplying agro-climatic information to rural farmers are inefficient (Fay Buckland & Campbell, 2021). Hence farmers are more likey to use radio.

**Table 4. 4** Multivariate Probit results on factors influencing farmers' choice of agrometeorological information pathway

| | **Radio** | | **Television** | | **Extension officer** | | **Mobile Internet** | |
|---|---|---|---|---|---|---|---|---|
| **Variable** | **Coef.** | **Std. Err.** | **Coef.** | **Std. Err.** | **Coef.** | **Std.Err.** | **Coef.** | **Std. Err.** |
| Age | 0.006 | 0.008 | -0.004 | 0.008 | 0.003 | 0.009 | 0.009 | 0.008 |
| Education | 0.034 | 0.022 | 0.098*** | 0.021 | -0.008 | 0.021 | 0.057** | 0.025 |
| Gender | 0.385** | 0.167 | 0.364** | 0.165 | 0.114 | 0.169 | 0.381** | 0.172 |
| Income | 0.212 | 0.245 | 0.254 | 0.285 | 0.041 | 0.307 | -0.395 | 0.263 |
| Farm | -0.003 | 0.009 | -0.001 | 0.009 | 0.010 | 0.011 | -0.000 | 0.009 |
| Household | 0.043 | 0.031 | 0.020 | 0.032 | -0.004 | 0.033 | 0.011 | 0.029 |
| Income Farming | 1.972*** | 0.700 | -0.089 | 0.701 | 0.938 | 0.690 | -0.835 | 0.849 |
| Market Distance | 0.016 | 0.049 | -0.025 | 0.049 | 0.009 | 0.044 | -0.018 | 0.053 |
| Credit Access | 0.384** | 0.166 | 0.354** | 0.163 | 0.117 | 0.166 | 0.235 | 0.180 |
| Extension Visits | -0.049 | 0.043 | 0.047 | 0.039 | 0.076* | 0.040 | -0.046 | 0.046 |
| Training | -0.127*** | 0.042 | 0.033 | 0.044 | 0.138*** | 0.045 | 0.019 | 0.048 |
| Group Membership | -0.063 | 0.191 | 0.164 | 0.192 | 0.186 | 0.191 | 0.112 | 0.213 |
| Internet Access | 0.679*** | 0.231 | -0.043 | 0.194 | -0.090 | 0.205 | 0.149 | 0.224 |
| Radio ownership | 0.822*** | 0.247 | 0.521** | 0.243 | 0.858*** | 0.266 | 0.819*** | 0.277 |
| TV ownership | 0.314 | 0.249 | -0.246 | 0.191 | -0.049 | 0.193 | -0.094 | 0.194 |
| Dissemination Language | 0.746*** | 0.258 | -0.147 | 0.254 | -0.424* | 0.247 | -0.171 | 0.277 |
| Repetitiveness | -0.004 | 0.048 | 0.057 | 0.044 | -0.008 | 0.045 | 0.032 | 0.046 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Climate shock exposure | 0.091 | 0.280 | -0.390 | 0.293 | 0.134 | 0.339 | -0.036 | 0.325 |
| Information Trust | 0.220 | 0.190 | 0.100 | 0.158 | -0.198 | 0.170 | -0.214 | 0.194 |
| Constant | -2.011 | 0.613 | -2.393 | 0.552 | -2.365 | 0.683 | -2.357 | 0.636 |

Number of obs = 423

Likelihood ratio test of rho21 = rho31 = rho41 = rho32 = rho42 = rho43 = 0: chi2(6) = 35.812

Wald chi2(76) = 261.07

Prob > chi2 = 0.0000

***, **, * Significant at 1%, 5% and 10%, respectively.

Farming decision-makers who own radio were more likely to access agrometeorological information through radio, television, extension officers, and mobile internet pathways. There was a significant relationship between radio ownership and use of radio, television, extension officers, and mobile internet as information pathways at 1%, 5%, 1% and 1% significance respectively. The efficient and reliable flow of agricultural information across the value chain (production, marketing and processing) depends on how well the information is packaged, distributed and shared. Utility derived from each agrometeorological information pathway varies across consumers of the disseminated knowledge. Moreover, farmers may wish to compare the information received from different pathways before making concrete investment decisions because these pathways can generally be used together either to substitute or complement each other. The study results corroborate the findings of Uzuegbu (2016) who noted that more progressive small-scale farmers seeking to expand and transform their farming activities use a combination of multiple information pathways to optimise benefits. For instance, radio and T.V use are comparatively cheap, flexible and adaptable ways to disseminate information or knowledge to a broader audience. However, radio appeals to the hearing organ alone, while TV is for audio-visuals; both address the general audience rather than specific problems facing farmers. They do not guarantee the relevant communication, timely, complete, accurate, and reliable information specific to rural farming households' problems. Moreover, Marsap and Narin (2009), found that extension officers and mobile internet pathways are convenient ways of delivering farm-specific solutions to problems facing individual farmers; therefore, more precise and reliable. They allow for two-way communication through question-and-answer sessions.

The use of comprehensible language positively associated with radio use but negatively associated with the use of extension officers as choices for information dissemination pathways. There was a significant relationship between language comprehensibility and use of radio at 1% and use of extension officers as information pathways at 1% and 10% significance levels respectively. This implies that radio broadcasted information in a more understandable language than the extension officers. The availability of information in an understandable language enhances farmers' capacity to adopt new agricultural technologies. The choice of agrometeorological information dissemination pathways is likely associated with accessibility of the pathway by the household or trust for information disseminated through the pathway as stated by the theory of diffusion and innovation, which states that a farmer's use of an invention is strongly associated to the appropriateness and relevance of a pathway. Farmers concurred that radio pathways relayed agrometeorological information in their local dialect, therefore highly understandable in its simplest form. Some extension officers may not understand the local language hence cannot disseminate information in a more comprehensible language to the farmers. Moreover, extension is demand driven and farmers may incur additional costs if they wish to get information from suitable extension workers. Similarly, Devkota and Phuyal (2018) intimated that radio used to relay agro-related information in the local language attracted more use among rural small scale farmers who opined that they understood such information completely. Contrary, the lack of effective agricultural extension officers likely constrains the use of extension as a preferred information pathway among sorghum farmers (Ncoyini *et al.*, 2022).

## 4.3 Effect of socio-economic, institutional and climate-related factors on access to agrometeorological information among smallholder sorghum farmers in Busia County.

The study identified important factors that influence access to agrometeorological information among farmers using a binary logistic model to provide policy information on which critical determinants to target. The binary logistic model odds ratio and their significance level are provided in Table 4.5. The econometric model results show Samia and Matayos sub-counties, farming experience, access to credit facilities, age of the decision-maker, owning a radio, access to internet services, and trust of agrometeorological information have significant relationships with access to agrometeorological information in Busia County. The marginal effects measure the change in the probability of access to agrometeorological information among sorghum farmers when the explanatory variable of interest changes by one unit. Furthermore, a robust standard error method is employed in the analysis for the four sub-counties. The logistic model shows that living in Samia decreases the probability of farmers accessing agrometeorological information by around 11% as compared to living in Teso South, while living in Matayos increases the probability of access by 8% as compared to living in Teso South. The study concludes that the marginal effects of some of the explanatory variables significantly vary.

### 4.3.1 Binary logistic regression model results for factors influencing access to agrometeorological information

The logistic model revealed that farmers living in Samia were less likely to access agrometeorological information by 11% as compared to the farmers who live in Teso South. The relationship between living in Samia and access to agrometeorological information was significant at 1% significance level. This can be explained by the proximity of the sub county to Lake Victoria hence main economic activity is fishing with farming being secondary to residents as it is done mostly on small scale. This reduces farmers, proactiveness in seeking for agrometeorological information. Additionally, Samia is a distance from important infrastructure that can enhance access to agrometeorological information hence limiting the probability of access. On the other hand, farmers living in Matayos are more likely to access agrometeorological information by 8.8% as compared to farmers living in Teso South.

There is a significant relationship between living in Matayos and access to agrometeorological information at 10% significance level. The plausible explanation to this finding is attributed to the sub-county's proximity to basic infrastructure such roads, agricultural offices and county headquarters which makes it easily accessible by the extension service provides and basic information and communication infrastructure (ICT), particularly internet service and electricity (Gbangou *et al.*, 2020). Moreover, the sub-county has good connectivity to electricity and telecommunication networks, which make the farmers to have easy access to agrometeorological information compared to those in Teso South. Matayos sub county is the heart of Busia County hence the easier access to information by farmers in this locality. Access to information is enhanced when the farmer is closer to the dissemination centres and Matayos being the headquarter of the county places the farmers within its environs at an advantage of accessing information and hence adoption of CSA practices.

**Access to credit facilities**. Access to credit facilities had the expected positive and significant effect on the probability of access to agrometeorological information. The logistic results reveal that access to credit facilities positively influenced access to agrometeorological information and was statistically significant at 5%. Those farmers who accessed credit had a higher probability of accessing agrometeorological information by 9% as compared to those who did not access credit. Access to credit facilities improves farmers' ability to increase investment in farming activities which in turn increases the need for agrometeorological information to facilitate making of informed decisions. Moreover, credit issuing farms also provide training and information to farmers who access credit in a bid to minimize the risks of losing investments. Farmers who access credit will also be more aggressive in seeking for information including paid information in order to make informed investment decisions in preparing for or responding to potential effects of climate variability. Access to affordable credit increases financial resources of farmers and their ability to meet transaction costs including access information on changing conditions hence influencing their decision (Nhemachena *et al*., 2014).

**Farming experience**. Increased farming experience increased the likelihood of a farmer accessing agrometeorological information. There was a significant relationship between farming experience and access to agrometeorological information at 5% significance level. The results shows an increased tendency of perceiving climate change with increasing experience as a result of observing changes over time giving rise to the need of accessing information that promotes adaptive capacity. Experienced farmers are more likely to possess greater knowledge about changes in climatic conditions. This is because they often hold leadership roles and are considered progressive within rural communities, making them prime targets for extension agents and facilitating easier access to agrometeorological information. Moreover, more experienced farmers have more sources of information build over time including indigenous information and a larger social network which enhances access to agrometeorological information. Mudombi-Rusinamhodzi *et al*. (2012) observe that as household heads age, gain education, and accumulate farming experience, their responsiveness to climate variability-induced hazards tends to improve. However, other research presents opposing conclusions. Kansiime *et al*. (2014) find that younger household heads are often more responsive than their older counterparts. This is attributed to the rapid pace of climate change, which has significantly altered established patterns of variability, leaving experienced farmers unprepared for new and unforeseen challenges.

**Table 4. 5** Logistic regression model results

| Variables | Odds Ratio | Std. Err. | z-Value | p>\|z\| | Mfx |
|---|---|---|---|---|---|
| Teso North | 0.750 | 0.358 | -0.60 | 0.547 | -0.026 |
| Samia | 0.271*** | 0.129 | -2.73 | 0.006 | -0.111*** |
| Matayos | 2.455* | 1.140 | 1.93 | 0.053 | 0.088* |
| Household size | 1.009 | 0.071 | 0.13 | 0.899 | 0.001 |
| Farming experience (Years) | 1.043** | 0.020 | 2.15 | 0.032 | 0.004** |
| Group membership | 0.867 | 0.370 | -0.33 | 0.739 | -0.013 |
| Frequency of extension visits | 1.155 | 0.102 | 1.64 | 0.102 | 0.013 |
| Access to credit facilities | 2.736** | 1.091 | 2.52 | 0.012 | 0.090*** |
| Distance to the market | 1.043 | 0.113 | 0.39 | 0.698 | 0.004 |
| Gender of the decision-maker | 0.952 | 0.380 | -0.12 | 0.901 | -0.044 |
| Age of the decision maker | 0.968 | 0.018 | -1.78 | 0.075 | -0.003 |
| Education level | 1.032 | 0.049 | 0.66 | 0.510 | 0.003 |
| Major income of decision maker | 0.763 | 0.932 | -0.53 | 0.599 | -0.024 |
| Land under farming (Acres) | 0.991 | 0.966 | -0.01 | 0.992 | -0.001 |
| Radio ownership | 5.166*** | 3.170 | 2.68 | 0.007 | 0.147*** |
| TV ownership | 0.718 | 0.340 | -0.70 | 0.485 | -0.030 |
| Access to internet services | 4.820*** | 2.090 | 3.63 | 0.000 | 0.140*** |
| Mobile phone ownership | 0.489 | 0.259 | -1.35 | 0.177 | -0.063 |
| Exposure to climate shocks | 0.633 | 0.324 | -0.89 | 0.371 | -0.041 |
| Trust in agromet information | 56.820*** | 23.321 | 9.84 | 0.000 | 0.361*** |
| Log likelihood ratio | | | | | -124.26 |
| Chi-square | | | | | 0.0000 |
| Wald chi2 (20) | | | | | 146.51 |
| Number of observations | | | | | 423 |

*P < 0.1, **P < 0.05, ***P < .001
Mfx - Marginal effects

**Radio Ownership**. As per the expectation owning a radio influenced the sorghum farmer's access to agrometeorological information positively and significantly at 1%. This implies that sorghum farmers who own radios have a 14.6% higher likelihood of accessing agrometeorological information than those who do not own one. Information is easily transmitted through mass media with radio being the most preferred as it covers a large audience. Most Information providers use channels that can reach a larger number of farmers and hence they use radio to disseminate information. This increases the likelihood of farmers who having a radio to access agrometeorological information. Most of the information is disseminated through radio stations (Keinembabazi, 2022). Therefore, most farmers who own radios are likely to receive more information than those who do not own one. The finding also conformed with (Onyango *et al.*, 2021) since radios are readily available and relatively easy to operate. Rural and community radio that use vernacular languages are preferred communication approaches that a larger proportion of smallholder farmers embrace. In addition, real-time meteorological information is highly perishable (Tuheirwe-Mukasa *et al.,* 2019); therefore, rapid dissemination through radio broadcast is the most efficient.

**Access to internet services.** The study reveals that access to internet services positively and significantly influenced sorghum farmers' access to agrometeorological information at 1% significance level. The logistic model results indicate that farmers who accessed internet service have a 14% higher probability of accessing agrometeorological information as compared to those who do not access. The world is opening up quickly, and internet services are becoming increasingly available including in the rural areas. Internet penetration increased from 29.5% in 2014 to 39.5% in 2015 (Tuheirwe-Mukasa *et al.,* 2019). The internet provides virtually all information needed in farming from production to post harvest handling and is one of the major instruments that can be used to access critical information on changes in weather expected by farmers in a particular period. Farmers can get vital information regarding weather and climate by just using their mobile phones and this has proved to be a good avenue for information dissemination. This is in line with the findings of Rathore (2020) who noted that today, through the internet and social media, farmers can easily interact and access information about weather and climate and get informed on how to manage their farming enterprises

**Trust in agrometeorological information.** As per the expectation, the study reveals that trust in agrometeorological information influenced the sorghum farmer's access to it positively and significant at a 1% significance level. The result implies that sorghum farmers who trusted the agrometeorological information had a 36% probability of accessing information more than those who did not trust it. Reliable information is important in improving the chances of farmers handling the changes expected in weather patterns hence most farmers would stick to information they feel they have confidence in from previous experiences. Farmers will look for more information if it is reliable, timely and accurate and will put more effort in accessing the information if it has worked for them before. Trusting agro-climate information, especially on the certainty of weather forecasts provided by the agro-met service providers, is important when accessing information (Nesheim *et al.,* 2017). Farmers are generally looking for accurate information. A study by Amegnaglo *et al.* (2017) found that the mean accuracy level of climate forecasts was about 77%, implying that eight of the ten forecasts were correct as per the service provider. Thus, farmers who are more confident with the agro-meteorological information are motivated to access it than those who are not confident.

## 4.4. Factors influencing the uptake of CSA practices among smallholder sorghum farmers in Busia County.

Two count models were estimated sequentially to determine which best explains the factors influencing the uptake of CSA practices among smallholder sorghum farmers. The standard Poisson model was estimated initially, with the results detailed in Table 4.6. To assess its suitability and performance, tests for goodness of fit and over-dispersion were conducted. Following this, the Negative Binomial Regression (NBR) model was estimated for comparison, which informed the choice of the most appropriate model. (Table 4.7).

The NBR model results revealed that the likelihood ratio test was not significant, as shown by alpha less than zero (1.8e-05), implying the NBR model was not a significant improvement over the standard Poisson model. Moreover, the data did not have an over-dispersion problem, as revealed by the test for the existence of this problem in the model.

The mean deviance and the Pearson chi-square ratio (the deviance and Pearson chi-square values divided by their degrees of freedom) were used to assess the degree of fit of the standard Poisson model as shown below;

Deviance/df = 198.2907/405 = 0.4896

Pearson/df = 265.9239/405 = 0.6566

where df refers to the degrees of freedom (405 in this case), these results for deviance (0.4896) and Pearson (0.6566) show that both ratios are significantly smaller than 1. Therefore, there is no evidence of the over-dispersion problem in the data. The standard Poisson model fits the data well.

**Table 4. 6** Standard Poisson results on determinants of uptake of climate-smart

| Variable | Coef. | Std.Err. | p-value |
|---|---|---|---|
| Age | -.002 | .003 | .513 |
| Education | .014* | .008 | .082 |
| Household size | .028** | .013 | .033 |
| Farm Experience | .005* | .003 | .091 |
| Income Farming | .323 | .251 | .198 |
| Own Farm | .164 | .173 | .343 |
| Credit Access | -.098 | .067 | .144 |
| Distance to Market | .03* | .017 | .081 |
| Extension Visits | .013 | .014 | .357 |
| Trainings | .166*** | .029 | 0 |
| Indigenous knowledge | .119* | .062 | .057 |
| SACCO Membership | .132 | .086 | .124 |
| Exposed to climate shocks | 2.522*** | .977 | .01 |
| Agro met Info Received | .048 | .033 | .144 |
| Agro met Info Trust | .18*** | .066 | .006 |
| Constant | -2.993 | .999 | .003 |
| LR test for the model $chi^2(17)$ = 2547.71 | | Prob > $chi^2$ | = 0.0000*** |
| Akaike crit. (AIC) = 880.880 | | Bayesian crit. (BIC) | = 1269.125 |

***, **, * = Significant at 1%, 5% and 10%, respectively

**Table 4.7** NBR model results on Determinants of Level of Uptake of Climate Smart Agricultural Practices

| Variables for Number_CSAstrategies | Coef. | Std.Err. |
|---|---|---|
| Age | -0.000 | 0.004 |
| Education level | 0.010 | 0.010 |
| Hhold size | 0.020 | 0.015 |
| Farm Experience | 0.003 | 0.004 |
| Prop income farming | 0.256 | 0.347 |
| Own farm | 0.218 | 0.213 |
| Distance Market | 0.023 | 0.022 |
| Access credit facilities | -0.045 | 0.075 |
| Extension visits | 0.023 | 0.018 |
| Member Farmers group | 0.001 | 0.090 |
| Topography | -0.064 | 0.078 |
| Number agromet infor | 0.026 | 0.067 |
| Training | 0.164*** | 0.042 |
| Exposed climate shocks | 3.408*** | 0.710 |
| Agromet infor trust | 0.229*** | 0.075 |
| Constant | -3.817 | 0.774 |
| lnalpha | -18.184 | 212.432 |
| Alpha | 1.27e-08 | 2.69e-06 |
| LR test of alpha=0: $chibar^2(01)$ = 1.8e-05 | | Prob >= chibar2 = 0.498 |
| LR test for the model $chi^2(17)$ = 338.970 | | Prob > chi2 = 0.000*** |
| Akaike crit. (AIC) = 1198.272 | | Bayesian crit. (BIC) = 1275.172 |

*** = Significant at 1%

Estimation of Akaike information criterion (AIC) and Bayesian information criterion (BIC) was done to determine the goodness of fit for the NBR model compared to the standard Poisson model (Table 4.8). For decision making, the lower values of one of the criteria (AIC) or (BIC) or both indicates the model is a better fit over the other. In this case, the AIC and BIC values for the NBR model were higher than those of the standard Poisson model, therefore, implying that the standard Poisson was a preferred model to the NBR model.

**Table 4. 8** AIC and BIC test for goodness of fit between Poisson and nbreg

| Model | Obs | ll(null) | ll(model) | df | AIC | BIC |
|---|---|---|---|---|---|---|
| poisson | 423 | -759.200 | -580.136 | 18 | 1196.272 | 1269.125 |
| nbreg | 423 | -749.621 | -580.136 | 19 | 1198.272 | 1275.172 |

Lower values of either AIC or BIC indicate a better fit

According to the estimates from the standard Poisson model, several socio-economic, institutional, and land characteristics significantly impacted the uptake of CSA practices among smallholder sorghum farmers in Busia County (Table 4.6). Out of the seventeen independent variables examined, eight were found to significantly influence the number of CSA practices adopted. These variables included education level, household size, farming experience, distance to market, the number of training sessions attended by farmers, exposure to indigenous climate knowledge, and trust in the agrometeorological information received. All eight variables were positively and significantly associated with the number of CSA practices adopted by the farmers.

Education of the decision maker positively and significantly affected the magnitude of uptake of CSA practices. There was a significant relationship between education level and uptake of CSA practices at 10% significance level. Education makes farmers to be more knowledgeable and progressive, hence improving their ability to perceive climate change and therefore take measures that help reduce the impact through uptake of CSA Practices. In this regard, educated farming households tend to look at the more result-oriented, cost-effective farming techniques, hence likely to adopt CSA technologies. Additionally, an educated farmer adopts farming activities with a predetermined approach based on insight from information acquired through education. Moreover, higher education enhances a farmer's ability to access, interpret, and utilize information, which positively influences their attitudes toward and openness to adopting CSA practices. Educated farmers are often more capable of analyzing the benefits of these practices, leading to greater adoption. Additionally, higher education levels facilitate access to off-farm employment opportunities, providing additional income that can be invested in adopting more CSA practices. Educated farmers are also generally more adept at grasping new concepts and ideas related to climate variability. This aligns with Deressa *et al*. (2009), who found that education improves awareness of climate variability by increasing farmers' capacity to access, process, and use relevant information for adaptation. Similarly, Onubuogu and Esiobu (2014) observed that educated farmers were better equipped with knowledge for responding to climate change strategies.

Households with more members were found to adopt a greater number of CSA practices compared to those with fewer members. The relationship between household size and CSA uptake was positively significant at the 10% level. Larger households may have a heightened need for food security due to their higher food requirements. This need drives them to seek out reliable agricultural practices that can ensure a stable and sufficient food supply. Consequently, they are more likely to invest in CSA practices that promise better yields and resilience against climate-related disruptions. a larger household often has more members capable of contributing to income generation. This additional income provides the financial means to invest in CSA practices. With more resources at their disposal, these households can afford to adopt and implement a wider range of climate-smart technologies and practices. Furthermore, the increased labor force resulting from a larger household size allows for more extensive agricultural activities which enables them to manage more complex or demanding CSA practices, which might involve tasks such as soil conservation, planting cover crops, or managing integrated pest control systems. Zou (2014) supports this by noting that larger family sizes typically provide more labour, enabling households to manage labour-intensive agricultural tasks more effectively. Similarly, Temesgen *et al*. (2008) found a positive correlation between larger household sizes and climate change adaptation, attributing this to the increased labour capacity that larger households possess. The availability of additional labour facilitates the successful implementation of CSA practices and contributes to improved agricultural productivity and resilience against climate variability.

Farmers with more farming experience are more likely to adopt more CSA practices as compared to those with less experience. There was a positive significant relationship between farming experience and uptake of CSA practices at 10% significance level. Busia county farmers had approximately 22 years of farming experience, revealing that they had spent most of their lifetime in farming as the main economic activity. This experience is necessary in promoting access to agrometeorological information and adoption of CSA practices. As farmers gain more experience in farming, they gain more skills and knowledge about climate variability and use a combination of both indigenous knowledge and modern weather information in making farming decisions. These experienced farmers are more likely to gain more knowledge through numerous trainings received over time hence they have more knowledge on how to access and utilize agrometeorological information in implementing different strategies on their farms. Years of farming experience likely provide farmers with valuable technical expertise, which can lead them to adopt a wide range of CSA practices across various enterprises based on their perceived benefits. Experienced farmers also have several years of farming and tend to implement different CSA practices over time depending on the prevailing climatic shocks hence accumulating a number of practices as experience increases making them have more practices. Additionally, experienced farmers are mostly viewed as progressive and influential in communities and are mostly targeted by extension officers and other stakeholders to act as lead farmers in promoting CSA practices. Many studies have revealed that experienced farmers tend to embrace more new technologies to solve the farming challenges experienced on the farms. These findings are consistent with Mogaka *et al*. (2021), who suggested that older farmers are more likely to adopt multiple CSA practices due to the accumulation of skills and knowledge gained over time. Similarly, Mudombi-Rusinamhodzi *et al*. (2012) observed that as household heads become older, gain more education, and accumulate additional farming experience, their ability to respond effectively to climate variability-related challenges tends to improve.

Farmers who were far from the market were more likely to uptake more CSA practices than those who were near the market. There was a positive significant relationship between distance to the market and uptake of CSA practices at 10% significance level. A long distance to the market can result in challenges accessing essential agricultural resources and services, potentially leading to a higher risk of losses and this may trigger the farmers to employ more CSA practices in order to reduce the potential loss. Farming households are socially oriented, so their preferred market outlet for input and output supplies is centrally located at a designated venue accessible to most participants. Most of these market outlets are situated where there is easy access to social amenities such as roads, water, electricity, and security. However, the purported central location for agricultural commodities is not closer to farming households' homes, considering the remoteness of these farms. Consequently, most farmers have to incur extra cost on transport, time, and sometimes meals while going to the market. It is rational that farming households invest in more CSA practices that do not require high input usage and reduce losses to avoid incurring high production costs. For example, farmers may opt to use resistant varieties to reduce the frequency of seeking chemicals from the market or a farmer may opt to practice minimum tillage if he cannot access a tractor easily as a result of longer distances. Farmers located far from markets may face challenges in accessing crucial services, such as agricultural inputs, market prices, and market trends. This increased difficulty heightens the risks for farmers, necessitating greater reliance on adaptation strategies to mitigate these risks. Consistent with this, Tesfaye and Seifu (2016) observed that market remoteness often leads farmers to favour multiple cropping systems and diversification rather than focusing on specialized crop cultivation.

The amount of agricultural training a farmer receives each year has a positive effect on their adoption of CSA practices. Providing education on new farming technologies facilitates knowledge exchange and heightens awareness of CSA methods, which in turn boosts the likelihood of these practices being adopted by smallholder farmers. Training programs aim to enhance household members' skills, thereby improving their circumstances and adaptability. Farmers with extensive extension contacts are better informed about changing climatic conditions and the management practices available for adaptation. This aligns with the theory of innovation diffusion and adoption, which suggests that increased awareness of new technologies and their benefits leads to higher adoption rates (Rogers *et al*., 2009). Ouédraogo *et al*. (2019) similarly observed that training on CSA practices, which includes productivity gains, soil enhancement, income improvement, and environmental benefits, contributes to greater adoption. In contrast, Arslan *et al*. (2014) found in Zambia that extension agents' involvement in multiple activities like input delivery and credit administration led to scepticism about their expertise, potentially diminishing trust and reducing implementation.

Farmers who embraced indigenous knowledge were more likely to uptake more CSA practices by 0.119 units as compared to those who did not utilize indigenous knowledge. Use of indigenous knowledge was significant at 10% level of significance. Indigenous knowledge is specific to the ecosystems and social conditions of a place because it encompasses a set of practices, beliefs and understanding about local ecology that has been shared across generations and hence when it is combined with the scientific knowledge, it enhances the farmers' ability to make informed decisions on how to adapt to climate variability. However, it should be noted that indigenous knowledge systems may differ and be more dynamic as they may draw on information from other places or they may be more conservative and tightly institutionalized. It is therefore important to adopt a hybrid system by integrating past experience of events and ways of learning and scientific knowledge for adaptation to expand. This is in line with the findings of Ouédraogo *et al*. (2018) who noted that 51% of the respondents use traditional knowledge including the state of stars, trees, insects, birds, wind or temperature to adapt to climate variability. The findings are also supported by McPherson *et al*. (2016) who noted that globally, indigenous people have shown detailed local ecological knowledge about biodiversity and value which can be tapped for greater impact conservation. Additionally, Lebel *et al*. (2013) also noted that local knowledge of physical indicators of imminent extreme weather or likelihood of a good or poor season would be useful to adapt better to current climate whether it was changing or not.

Farmers who have experienced climate shocks in the past are more inclined to adopt a variety of Climate-Smart Agriculture (CSA) practices. The impacts of climate change and variability play a crucial role in motivating farmers to implement CSA strategies that enhance their resilience and protect against future events. Those who have encountered climate-related challenges are often more proactive in preparing for potential future occurrences by adopting additional CSA practices. For example, smallholder farmers facing irregular rainfall, increasing temperatures, reduced rainy seasons, floods, and pest or disease issues are more likely to engage in practices such as crop diversification, planting drought-resistant varieties, and mulching (Tanti *et al*., 2022). The selection and extent of CSA practices adopted are influenced by the type and frequency of climate shocks experienced, with more frequent shocks typically leading to a greater adoption of various CSA strategies.

Trust in agrometeorological information services significantly enhances the uptake of Climate-Smart Agriculture (CSA) practices. Reliable and timely information allows farmers to make informed decisions with reduced risk of losses. Effective agrometeorological information should be accurate, accessible, cost-effective, and practical, supporting farmers in planning and timing various agricultural activities such as land preparation, planting, seed selection, weeding, fertilization, and harvesting (Djido *et al*., 2021). Interactions with farmers have highlighted that dependable agrometeorological data is invaluable, helping them choose CSA practices that yield the best results and fostering confidence in these practices (Ouedraogo *et al*., 2018). Additionally, long-term CSA practices are often viewed more favorably than short-term ones because they assist in comparing past and current production levels and aid in future forecasting and planning. Access to trustworthy information enhances farmers' decision-making abilities, increasing the likelihood of adopting CSA practices. Accurate and comprehensive agro-based information is a crucial resource, enabling farming households to implement a variety of CSA practices effectively to mitigate climate change impacts (Musafiri *et al*., 2020). CSA practices offer both short-term and long-term benefits and can either complement or substitute each other. Farmers equipped with reliable agrometeorological information are better positioned to strategically plan their farming operations, leveraging multiple CSA practices to optimize productivity, as supported by Qazlbash *et al*. (2021).

## 4.5. Evaluation of the effect of adaptation to climate variability, agrometeorological information, socioeconomic and institutional factors on agricultural productivity among sorghum farmers in Busia County.

The impact of agrometeorological information, along with socioeconomic and institutional factors, on climate variability adaptation was assessed using the Endogenous Switching Regression (ESR) model, as indicated by the results in Table 4.9. The ESR model employs a two-step approach: initially, a Probit model is used to estimate the adoption decision, followed by a joint estimation of selection and outcome equations using the maximum likelihood method. The model achieved convergence efficiently, as indicated by a log-likelihood value of -662.93418. Additionally, the Wald chi-square statistic was used to evaluate the overall model fit and the significance of the variables. (Wald $Chi^2$ (9) =42.48, Prob> $Chi^2$ =0.0000) suggest that the model fits the data well and demonstrates strong explanatory power. Key factors influencing farmers' adaptation to climate variability included the number of extension contacts, access to credit, gender, education, other income activities, and training. Conversely, gender and the proportion of income derived from farming were significantly associated with those who did not adapt to climate variability.

Farmers who had more frequent extension contacts were significantly more likely to adapt to climate variability, with the relationship being statistically significant at the 1% level. Specifically, each additional extension contact increased the likelihood of adaptation by approximately 11.86%. This positive effect is likely because extension services provide crucial information on effective climate-smart agricultural practices and bolster the resilience of farmers facing climate change impacts. Furthermore, increased interaction with extension services typically results in more comprehensive information on climate change and variability, aiding farmers in making better-informed decisions and enhancing their preparedness for potential challenges. Extension officers also offer practical training through demonstrations on different ways of adapting to climate variability which enhances the farmers’ skills and knowledge on adaptation. The findings align with those of Legesse *et al*. (2013) and Ozor and Nnaji (2011), who also identified a strong link between access to extension services and effective adaptation to climate variability. Additionally, the growing demand for extension services underscores the necessity for ongoing training of personnel to equip them with the skills needed to address climate change risks effectively.

Farmers who accessed credit were found to be less likely to engage in adaptation strategies for climate variability. The significant relationship between credit access and adaptation to climate variability at the 1% level indicates that credit access decreased the likelihood of adaptation by approximately 29.98%. This can be attributed to the fact that while credit provides essential financial resources, farmers often face multiple immediate needs, such as education, food, and healthcare, which take priority. Consequently, these urgent needs absorb most of the credit funds, leaving limited resources available for investing in climate adaptation measures. Adaptation strategies, such as purchasing new planting materials and adopting advanced technologies, can be capital-intensive. Therefore, when resources are allocated to cover immediate needs, it becomes challenging for farmers to invest in comprehensive adaptation measures. Additionally, some farmers might opt to save the credit as a precautionary measure against future climate-related impacts, rather than using it for immediate adaptation efforts. This is particularly common among farmers who prefer to keep funds available for purchasing food and other essential commodities in case of crop failures due to climate change. These findings are consistent with Ojo and Baiyegunhi (2020), who reported that credit constraints have a detrimental effect on the ability of farmers to implement climate adaptation strategies. Financial resources play a crucial role in expanding and strengthening strategies to mitigate the risks associated with climate change. Without adequate credit, farmers may struggle to adopt effective adaptation measures, highlighting the need for improved access to and management of financial resources to support climate resilience in agriculture.

Male decision-makers were less inclined to adopt climate adaptation strategies, showing a significant non-adoption tendency at the 1% level and a lower likelihood of adaptation at the 10% significance level. Conversely, female farmers were more likely to adopt climate variability adaptation practices, with a 19.89% higher likelihood of doing so. This greater propensity among women can be attributed to their predominant involvement in farming within rural settings, as men often pursue alternative income sources. Consequently, women may be more motivated to implement strategies that ease household burdens and improve farm productivity. Women's higher adaptation rates are also linked to their generally risk-averse nature compared to men. They may prefer to adopt strategies that mitigate risks rather than engaging in high-risk ventures. This observation aligns with findings from Baten and Khan (2010) and Bewke and Alemu (2011), who noted that female-headed households are more proactive in adopting climate change adaptation strategies. This is particularly evident in rural smallholder communities, where women typically handle much of the agricultural labor while men are less involved in farming activities. However, this contrasts with the views of Kakota and Wambugu (2011), who argue that women face greater vulnerability to food insecurity due to limited adaptation options compared to men. Despite the differences, it is clear that female farmers' active engagement in agricultural work and their greater inclination towards risk management influence their adoption of climate adaptation practices.

Farmers with higher levels of education were more likely to adopt strategies to address climate variability. The relationship between education level and adaptation was found to be significant at the 1% level, with each additional level of education increasing the likelihood of adaptation by 3.88%. Higher education enhances a farmer's ability to access, understand, and process relevant information, thereby improving their risk perception and management capabilities. Educated farmers are often better equipped to identify and implement effective adaptation strategies due to their increased knowledge and progressive outlook. Moreover, higher education often provides farmers with opportunities for off-farm employment, generating additional resources that can be invested in adaptation practices. The benefits of education extend beyond just acquiring knowledge; it also fosters improved attitudes and decision-making abilities, which can enhance socioeconomic status, social capital, and overall adaptive capacity. These findings align with Ojo and Baiyegunhi (2020), who demonstrated that higher education levels boost farmers' ability to adapt to climate variability. Similarly, Onubuogu and Esiobu (2014) reported that educated farmers, with their greater knowledge and understanding of climate change strategies, are more adept at selecting appropriate adaptation options.

Households who had other income generating activities in addition to farming were less likely to adapt to climate variability. There was a negative relationship between off farm income and adapters to climate variability at 10 per cent significance level. This implies that having off farm income reduced the chances of a farmers adapting to climate variability by 33.32 per cent. Farmers who have alternative sources of income may not commit all their attention and resources to agricultural activities because they know that in case of failure, they have a fall-back plan therefore they may not be interested in implementing adaptation strategies. On the other hand, farmers who do not have any alternative source of income will invest all their efforts in farming including adaptation to climate variability to reduce the probability of failure as it is the only source of their livelihood. This is in line with the findings of Zou (2014) who noted that farmers who are involved in off-farm work frequently allocate much of their time to these secondary occupations, which can reduce their focus on agricultural activities. Consequently, they may pay less attention to farming and be less inclined to adopt adaptation strategies. Moreover, Shongwe (2014) also argues that farmers who rely exclusively on agriculture for their livelihood have more time and resources to explore various adaptation options and focus their efforts on enhancing their agricultural practices. In contrast, those with additional sources of income might not allocate as much attention or resources to farming, limiting their ability to fully engage with adaptation strategies.

Households which allocated a larger proportion of their income to farming were more likely to adapt to climate variability than those who allocated less income. A positive relationship was observed between a higher proportion of income dedicated to farming and adaptation to climate variability, significant at the 10% level. The results suggest that increasing the share of income invested in farming enhances the likelihood of farmers adopting adaptation measures to climate variability by 101.07%. Small-scale sorghum farmers in Busia allocated an average of 15% of their income to finance farming activities as a business, a proportion likely low to transform their farming activities from sustainable to business oriented or even support implementation of adaptation strategies. Adapting to climate change is not only pegged on the amount allocated to farming as there are other inputs to be considered which may be expensive and use a large amount of resources allocated to farming. Additionally, rights to resources such as land will also determine the level of adaptation as people who lease land may allocate more income to farming but they do not have the full rights of investing in permanent structures on the farm to adapt to climate variability. This contrasts with the findings of Fosu-Mensah *et al*. (2010), which indicated that higher farm income positively influenced farmers' decisions to adapt to climate variability rather than choosing not to adapt.

**Table 4. 9** Maximum Likelihood Estimates of Endogenous Switching Regression Model

| Variables | Selection Model | | Adapters to climate Variability | | Non-adapters to Climate Variability | |
|---|---|---|---|---|---|---|
| | **Coef.** | **p>/Z/** | **Coef.** | **p>/Z/** | **Coef.** | **p>\|Z\|** |
| Group membership | -0. 4163** | 0.023 | -0.1306 | 0.303 | 0.1488 | 0.313 |
| Extension contacts | 0.1340*** | 0.004 | 0.1186*** | 0.000 | -0.0233 | 0.540 |
| Credit access | 1.4791*** | 0.000 | -0.2998*** | 0.071 | 0.3557 | 0.105 |
| Market distance | 0.0885* | 0.079 | -0.0017 | 0.957 | -0.0233 | 0.636 |
| Gender | 0.2446 | 0.149 | -0.1989* | 0.085 | 0.4138*** | 0.003 |
| Age | 0.0029 | 0.638 | -0.0007 | 0.864 | -0.0028 | 0.585 |
| Education level | -0.0448** | 0.033 | 0.0388*** | 0.005 | 0.0232 | 0.220 |
| Income activities | 0.3399 | 0.126 | -0.3332* | 0.087 | 0.0670 | 0.755 |
| Incomeprop_farming | 1.2476* | 0.098 | -0.0113 | 0.982 | 1.0107* | 0.080 |
| Number of trainings | 0.2493*** | 0.001 | 0.0633** | 0.027 | -0.0082 | 0.809 |
| Own_farm land | 0.2599 | 0.470 | -0.0641 | 0.815 | 0.1450 | 0.532 |
| No_agro-metrological | -0.2694** | 0.028 | | | | |
| Trust in agro-metrolinfor | 0.8564 | 0.000 | | | | |
| _cons | -1.7792*** | 0.002 | 6.6795*** | 0.000 | 4.9150*** | 0.000 |
| Number of observations | 423 | | | | | |
| Wald $chi^2(9)$ | 42.48 | | | | | |
| Log likelihood | -662.93418 | | | | | |
| Prob > $chi^2$ | 0.0000 | | | | | |

*, **, *** represents 10%, 5% and 1% significance level, respectively

Farmers who received more trainings were more likely to adapt to climate variability. There was a positive relationship between number of trainings and adapters to climate variability at 5% significance level. The results indicate that having an extra training increases the chances of a farmer adapting to climate variability by 6.33%. Trainings empower farmers with knowledge on different topics in farming including adaptation practices available and how to implement them. This increases awareness of CSA practices and therefore enhance their adoption rate among smallholder farmers. Training also improves the skills of household members to be able to perceive climate change, its impacts and the importance of implementing CSA practices to mitigate and adapt. Farmer also gives farmers a wider choice of alternatives based on farmer-specific needs and affordability. This is in line with the findings of Zakaria *et al*. (2020) who found that that training farmers on CSA practices in Kenya enhanced the adoption of adaptation strategies. Similarly, Ouédraogo *et al.* (2019) found that more training on adopting CSA practices such as increased productivity, soil improvement, and environmental conservation was key for farmers enhanced uptake. Additionally, this aligns with the theory of diffusion and adoption of innovations, which posits that increased awareness of existing and new farming technologies, along with their benefits, enhances the likelihood of farmers adopting these innovation (Rogers *et al.*, 2009).

### 4.5.1 The Treatments Effects on Sorghum Yield

Table 4.10 presents the impact of climate variability adaptation on sorghum yield. The initial step involved assessing whether adaptation to climate variability was endogenous. To determine this, Durbin and Wu-Hausman tests were conducted and the results were as follows; Durbin (score) $Chi^2$ (1) = 8.49397 (p= 0.0036) and Wu-Hausman F (1, 409) = 8.38114 (p= 0.0040). Given the p-values of less than 0.05, the Durbin and Wu-Hausman tests were significant, leading to the rejection of the null hypothesis that adaptation to climate variability was exogenous. This indicates that adaptation to climate variability was indeed endogenous in the model. Additionally, the Sargan and Basman tests for over-identifying restrictions yielded p-values of 0.2656 and 0.2729, respectively, both greater than 0.05. This result means that we failed to reject the null hypothesis, which suggests that there are no over-identifying restrictions present. Furthermore, the coefficients for the two instrumental variables—namely, the number of agro-meteorological information sources and trust in agro-meteorological information—were jointly significant, with an F-statistic of 15.8779 (Prob > F = 0.0000). This confirms that the instruments used in the model were valid.

**Table 4. 10** Mean Treatment Effect on Sorghum Yield

| **Sub-sample** | **Decision** | | |
|---|---|---|---|
| | **Adapters to Climate Variability (ATT)** | **Non adapters to Climate Variability (ATU)** | **Average Treatment Effects (ATE)** |
| Adaptation to climate variability | (a)6.43 | (c)5.55 | 0.88*** |
| Non- adapters to climate Variability | (d)7.11 | (b) 5.74 | 1.37*** |
| **Heterogeneity Effects** | **$BH_1$= -0.68** | **$BH_2$= -0.19** | **-0.49** |

*** significance at 1%

The values labeled (a) and (b) represent the actual observed sorghum output for farmers who adapted to climate variability and those who did not, respectively. Conversely, values (c) and (d) depict the counterfactual expected sorghum output for adapters and non-adapters to climate variability, respectively. The analysis reveals that the Average Treatment Effect on the Treated (ATT) had a significant negative impact on sorghum output at the 1% level. Specifically, if farmers who adapted to climate variability had not adopted these practices, their average sorghum output would have decreased by 0.88. Conversely, the Average Treatment Effect on the Untreated (ATU) shows a significant negative impact on sorghum output due to adaptation to climate variability among non-adapters at the 1% level. Non-adapters would have seen an increase in sorghum output by 1.37 if they had adopted climate variability adaptation practices.

Both groups, those who adapted to climate variability and those who did not, require targeted strategies to address climate variability, as the Average Treatment Effect (ATE) was positive for both. Specifically, BH1 of -0.68 indicates that 68% of non-adapters would have outperformed adapters if they had adopted climate variability practices. Conversely, BH2 of -0.19 shows that 19% of adapters would have performed better than non-adapters if they had not adopted such practices. The negative transitional heterogeneity of -0.49 suggests that the differences in sorghum output are attributed to unobserved household characteristics rather than the adaptation practices themselves. Overall, adaptation to climate variability is crucial for improving sorghum output, as those who adapted generally achieved higher yields compared to those who did not.

# CHAPTER FIVE

# CONCLUSIONS AND RECOMMENDATION

## 5.1 Conclusions

i. From the descriptive statistics, findings reveal that the mean age of farming decision-makers was approximately 49 years, and they had an average of 9 years of education. Farmers had approximately 22 years of farming experience, implying that most farmers had spent the main part of their lifetime farming. An average of 72% of the farmers belonged to the farmers' group, and approximately 44% had access to internet services enabling them to receive agrometeorological information. An average of 59% of the decision-makers owned radio as an agrometeorological information dissemination pathway, while 41 % owned TV. The mean uptake of CSA practices by farmers was 2 in a period of one year. The few CSA practices adopted could be explained by the small size of the farming land owned by farmers in the study area leading to the farmers choosing a given number of CSA practices depending on the acreage of the land under production.

ii. Evaluation of the choice of selected agrometeorological information dissemination pathways by small-scale sorghum farmers, revealed that Literate farmers were more likely to use television and mobile-internet information dissemination pathways attributed to enhanced knowledge and the need for wider agrometeorological information from multiple reliable and efficient pathways. Access to credit facilities gives farming households an incentive to seek information concerning adaptation to climate variability using multiple pathways. Use of easily understandable language and comprehensible methods to disseminate information is key in determining choice of a dissemination pathway. Most Sorghum farmers less preferred public extension services because they are ineffective in terms of the language and methods used to disseminate information.

iii. Assessment of factors influencing access to agrometeorological information among revealed that location of the smallholder farmers, experience of the information user, possession of communication tools such as radio and access to internet services influenced access to agrometeorological information among the sorghum farmers. The location/ residence of the small-holder farmers enhances access to critical infrastructure for relaying information, such as electricity, roads, and telecommunications. Farming experience is instrumental as farmers use knowledge acquired over time combined with indigenous knowledge to make agricultural decisions change. Access to credit facilities and internet services are key ingredients in enhancing farmers' ability to access agrometeorological information. Climate change distorts weather patterns; therefore, accessing agrometeorological information is vital to both young and old farmers. Communicating trusted information regarding the weather motivates small-holder farmers to search for and access agrometeorological information.

iv. Level of education, access to training, indigenous knowledge, exposure to climate shocks and trust in agrometeorological information are key in determining the uptake of CSA practices. Farmers with higher education are likely to embrace CSA practices because of their knowledge levels. Trainings enlightens farmers and promotes knowledge sharing about the reality of climate change and how the effects can be handled hence promoting adoption. Possession of indigenous knowledge is closely related with experience and allows farmers to blend the traditional knowledge with modern knowledge hence improving their adoption level. Previous exposure to climate shocks drives farmers to improve their preparedness to future shocks by adopting CSA practices. Reliable agrometeorological information aids farmers in making informed and reliable decisions in preparation for climate change eventualities.

v. The endogenous switching regression model results indicated that adapters to climate variability had received more extension contacts, had a greater number of trainings and were more educated. At the same time, credit access and off farm income had a negative effect on adaptation. Extension training and education enhances the knowledge base of the farmers and therefore increasing their probability to adapt to climate variability. On the other hand, credit accessed by the farmer may not necessarily be invested in adaptation as there is trade-off between many needs which may lead to diversion of the received credit. Farmers with off farm income may treat farming as part-time and may not see the need of investing in comprehensive adaptation strategies. The mean treatment effect from the analysis of the effect of climate variability, agrometeorological information and institutional factors on agricultural productivity revealed that sorghum yield was higher among adapters to climate variability than the non-adapters. The highlighted results reveal the need to enhance full-scale CSA practices adoption among small-scale sorghum farmers who are vulnerable to climate change variabilities

## 5.2 Recommendations

The following strategies and policies could be formulated based on the findings above.

i. The government should consider expanding internet band width to cover more areas and improve farmers access to agrometeorological information. The Kenya Meteorological Department, Research institutions and other private actors should utilize radio as a major information dissemination pathway since it is more reliable and has a wide reach among the farming community. Extension service providers should target farmer groups in disseminating of agrometeorological information as majority farmers belong to groups which have a larger multiplier effect in dissemination of information.

ii. Agrometeorological dissemination agencies including KMD should properly package agrometeorological information in a more understandable language through efficient and reliable information dissemination pathways to build confidence and trust in the relayed information among sorghum farmers. The different government levels should support continuous training and retraining of extension officers about climate variability and the new coping and adaptation strategies and their implication for agricultural productivity in the study area. Through the ministry of agriculture, in coordination with other development partners/stakeholders, the government could create more avenues for extension services, including hiring more qualified extension officers capable of disseminating information in rural communities using local languages and ensuring they are accessible and available at all times. There is a need to have efficient collabouration between researchers (producers of agrometeorological information) and extension officers for the latter to be effective in their service delivery to farmers. The agricultural policy that seeks to enhance farmers' utilisation of agrometeorological information dissemination pathways and how to employ effective pathways among farmers to ensure maximum benefits is recommended.

iii. Both National and County governments should focus on improving rural infrastructure such as roads, electricity access, and telecommunication networks to ensure that small-holder farmers conveniently access agrometeorological information. Financial institutions should package credit facilities that are tailor made to farmers needs to encourage many farmers to access and utilize credit in accessing agrometeorological information. To ensure effectiveness and optimum efficiency, agrometeorological information should be farmer specific and tailored to suit both young and old farmers. Agro-met advisors such as KMD should give reliable information that can be used by farmers to make informed decisions since unreliable information can result in farmers incurring losses, discouraging them from accessing the information in the future.

iv. Regular and enhanced training programs are essential to provide farmers with critical skills, such as project appraisal through cost-benefit analysis, which can help them invest in profitable climate-smart agricultural (CSA) practices. Additionally, improving agrometeorological dissemination pathways is crucial for farmers to gain access to the skills and strategies needed to effectively combine both modern and traditional agricultural technologies in a cost-effective manner. Relevant institutions like Kenya Meteorological Department, research institutions and other private actors should ensure dissemination of accurate and reliable information that farmers can depend on for decision making.

v. Policymakers, government institutions, and non-governmental organizations should work to enhance the frequency of extension services and foster educational and training opportunities for farmers. This will help to increase their awareness of the different types of agrometeorological information available and improve their ability to use this information to make well-informed decisions that can boost agricultural productivity. Financial institutions should ensure they offer training to farmers on financial literacy before issuing credit in order to enhance prudent utilization of the funds.

## 5.3 Areas of Further Research

The study established that using extension services and mobile internet was practised mainly by the elite, economically/financially capable and large-scale farmers. At the same time, most opted for radio and TV. Moreover, internet use was found to have unlimited information tailored towards specific farmers' needs. From the preceding, the study recommends the need for future research that could consider the cost-benefit analysis for the various CSA practices to enable farmers to make sound choices on the most effective practices to adopt. For future research, it is recommended to explore farmers' willingness to adopt Climate-Smart Agriculture (CSA) practices. This could provide valuable insights into how farmers' willingness influences their behavioural choices regarding these practices. Understanding this dynamic could help tailor strategies to better support and encourage CSA adoption. The expected results could help explain farmers' CSA practices adoption behaviour concerning the preferred choice.

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## APPENDICES

**Appendix A**: Variables included in the Multivariate Probit model and expected signs

| Variable | Definition of variable and their measurement | Expected sign |
|---|---|---|
| **Dependent Variable** Choice of agrometeorological information pathways | Information dissemination pathways (Binary 1 yes 0 otherwise) | |
| **Independent Variables** | | |
| Age | Age of the decision maker[1] in Years | ± |
| Education | Education level of decision maker years | ± |
| Gender | Gender of decision maker (1 male, 0 otherwise) | ± |
| Occupation | Main income activity of the decision maker (1 farming, 0 otherwise) | ± |
| Experience | Farming experience of decision maker in years | ± |
| Household size | Household size (adult proportion) | ± |
| Income | Proportion of income allocated to farming (KES[2]) | ± |
| Market distance | Distance to the market (walking minutes) | ± |
| Credit | Amount of credit received in the last 12 months (KES) | ± |
| Extension | Number of extension visits in the last 12 months (Continuous) | ± |
| Training | Number of trainings attended in the last 12 months (Continuous) | ± |
| Group membership | Membership to agriculture related group (1yes, 0 otherwise) | ± |
| Insurance | Access to crop insurance (1 yes, 0 otherwise) | ± |
| Internet | Access to internet services (1 yes, 0 otherwise) | ± |
| Radio | Ownership of radio (1yes, 0 otherwise) | ± |
| Television | Ownership of television (1 yes, 0 otherwise) | ± |
| Mobile phone | Ownership of mobile phone (1 yes, 0 otherwise) | ± |
| Language | Language used in disseminating the information (1 comprehensible, 0 otherwise) | ± |
| Repetitiveness | Number of times the information is shared (number of times in the past 1 month) | ± |

[1] Decision maker is the individual who makes major household decisions including farming

[2] KES – Kenya Shillings

**Appendix B**: Variables included in the Logit model and expected signs

| Variable | Definition of variable and their measurement | Expected sign |
|---|---|---|
| **Dependent Variable** Access to agrometeorological information | Whether one receives agrometeorological information or not (1= Access, 0 otherwise) | |
| **Independent Variables** | | |
| Age | Age of the decision maker[1] in Years | ± |
| Education | Education level of decision maker years | ± |
| Gender | Gender of decision maker (1 male, 0 otherwise) | ± |
| Occupation | Main income activity of the decision maker (1 farming, 0 otherwise) | + |
| Experience | Farming experience of decision maker in years | ± |
| Household size | Household size (adult proportion) | ± |
| Income | Proportion of income allocated to farming (KES[2]) | + |
| Land size | Proportion of land under farming (hectares) | ± |
| Market distance | Distance to the market (walking minutes) | ± |
| Credit | Amount of credit received in the last 12 months (KES) | ± |
| Extension | Number of extension visits in the last 12 months (Continuous) | ± |
| Group membership | Membership to agriculture related group (1 yes, 0 otherwise) | ± |
| Insurance | Crop insurance (1 yes, 0 otherwise) | ± |
| Radio Ownership | Ownership of radio (1 yes, 0 otherwise) | ± |
| Television Ownership | Ownership of television (1 yes, 0 otherwise) | ± |
| Internet | Access to internet services (1 yes, 0 otherwise) | ± |
| Mobile phone | Ownership of television (1 yes, 0 otherwise) | ± |
| Topography | Land topography (1 flat, 0 otherwise) | ± |
| Drought | Exposure to drought in the last 2 years (1 yes, 0 otherwise) | + |
| Floods | Exposure to floods in the last 2 years (1 yes, 0 otherwise) | + |
| Hailstorm | Exposure hailstorm in the last 2 years (1 yes, 0 otherwise) | + |

[1] Decision maker is the individual who makes major household decisions including farming

[2] KES – Kenya Shillings

**Appendix C**: Variables included in double hurdle model and expected signs

| Variable | Definition of variable and their measurement | Expected sign |
|---|---|---|
| **Dependent Variable** Level of uptake of climate smart agricultural practices | Number of CSA strategies implemented (continuous) | |
| **Independent Variables** | | |
| Age | Age of the decision maker[1] in Years | ± |
| Education | Education level of decision maker years | ± |
| Gender | Gender of decision maker (1 male, 0 otherwise) | ± |
| Occupation | Main income activity of the decision maker (1 farming, 0 otherwise) | + |
| Household size | Household size adult proportion | ± |
| Experience | Farming experience of decision maker in years | ± |
| Income | Proportion of income allocated to farming (KES) | + |
| Land size | Proportion of land under farming (hectares) | ± |
| Land tenure | Ownership of land (1 owned, 0 otherwise) | ± |
| Market Distance | Distance to the market (walking minutes) | ± |
| Credit | Amount of credit received in the last 12 months (KES) | ± |
| Extension | Number of extension visits in the last 12 months (Continuous) | ± |
| Training | Number of trainings in the last 12 months (Continuous) | ± |
| Group membership | Membership to agriculture related group (1 yes, 0 otherwise) | ± |
| Insurance | Access to crop insurance (1 yes, 0 otherwise) | ± |
| Land Topography | Land topography (1, flat 0, otherwise) | ± |
| Agrometeorological Information | Access to agrometeorological information (number of times in the last 12 months) | |
| Drought | Exposure to drought in the last 2 years (1 yes, 0 otherwise) | + |
| Floods | Exposure to floods in the last 2 years (1 yes, 0 otherwise) | + |
| Hailstorms | Exposure hailstorm in the last 2 years (1 yes, 0 otherwise) | + |

[1] Decision maker is the individual who makes major household decisions including farming

[2] KES – Kenya Shillings

**Appendix D**: Variables included in the endogenous switching regression model and expected signs

| Variable | Definition of variable and their measurement | Expected sign |
|---|---|---|
| **Dependent Variable** Adaptation to climate variability | Use of one or more adaptation strategy (1=yes, 0 otherwise | |
| **Independent Variables** | | |
| Age | Age of the decision maker[1] in Years | ± |
| Education | Education level of decision maker years | ± |
| Gender | Gender of decision maker (1 male, 0 otherwise) | ± |
| Occupation | Main income activity of the decision maker (1 farming, 0 otherwise) | + |
| Household size | Household size adult proportion | ± |
| Experience | Farming experience of decision maker in years | ± |
| Income | Proportion of income allocated to farming (amount in KES) | ± |
| Land size | Proportion of land under farming (hectares) | ± |
| Land tenure | Ownership of land (1 owned, 0 otherwise) | ± |
| Market distance | Distance to the market (walking minutes) | ± |
| Credit | Amount of credit received in the last 12 months (KES[2]) | ± |
| Extension | Access to extension services (number of extension visits in the last 12 months | ± |
| Training | Number of trainings in the last 12 months (Continuous) | ± |
| Group membership | Membership to agriculture related group (1 yes, 0 otherwise) | ± |
| Insurance | Access to crop insurance (1 yes, 0 otherwise) | ± |
| Topography | Land topography (1 flat, 0 otherwise) | ± |
| Agrometeorological Information | Access to agrometeorological information (number of times in the last 12 months) | + |
| Drought | Exposure to drought in the last 2 years (1 yes, 0 otherwise) | + |
| Floods | Exposure to floods in the last 2 years (1 yes, 0 otherwise) | + |
| Hailstorms | Exposure hailstorm in the last 2 years (1 yes, 0 otherwise) | + |

[1] Decision maker is the individual who makes major household decisions including farming

[2] KES – Kenya Shillings

**Appendix E**: Questionnaire

Respondent,

My name is Atsiaya Godfrey a postgraduate student at Egerton University, Njoro Campus.In partial fulfilment of the requirements for Doctor of Philosophy in Agricultural Economics, I am conducting a research entitled: "***agrometeorological information and adaptation to climate variability among smallholder sorghum farmers in busia county, kenya***". I kindly request your assistance by completing the questionnaire below. Your input is valuable to this study. Please be assured that participation is entirely voluntary, and any information provided will be kept confidential. The data collected will be used solely for the purposes of this research.

This survey intends to interview the head of household who is above 18 years of age and is responsible for household farm decision making.

Questionnaire number……………………

Date of interview (dd-mm-yyyy) ……………

Name of interviewer…………………….

**SECTION A: HOUSEHOLD INFORMATION**

1.1 Sub county……………… 1.2 Ward ……………1.3 Sub location ……………………

1.4 Village……………………..

1.5 Name of respondent……………………… 1.6 Phone number…………………..

1.7 Please complete the table below with the first names of all household members, including the Head of Household (HH), spouse, and other members, using the provided codes. 'A household is defined as a group of people currently eating from the same pot under the same roof or same compound for households with more than one structure for a period of at least four months a year'.

1.7.1 Household number……………………………………

| HH member code | 1.7.2 Sex 1=male 2=female | 1.7.3 Relation to Head | 1.7.4 Age in years | 1.7.5 Years of formal education completed | 1.7.6 Major income activity | 1.7.7 Marital Status |
|---|---|---|---|---|---|---|
| **Respondent** | | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Household Head** | | | | | | |
| | | **Codes:**<br>1=Head<br>2=Spouse<br>3=Son/daughter<br>4=House help<br>5=other | | | **Codes**<br>1=salaried employee<br>2=Business person<br>3= casual labourer<br>4=farming<br>5=other | **Codes**<br>1=Married,<br>2=Single,<br>3= separated<br>4= Divorced<br>5=Widow/Widower |

**SECTION B: FARM ENTERPRISE**

**2.1** Land ownership; please fill in the table below

Total land size owned by the hhold in (acres)………………………

| 2.1.1 Method of Land acquisition | Land size in acres | 2.1.2 Tenure system<br>1. Private with title deed 2. Private without title deed<br>3. Communal 4. Other…………… |
|---|---|---|
| 1. Allocated by clan | | |
| 2.Inherited from parents | | |
| 3. Bought | | |
| 4. Rented | | |
| 5. Gifted | | |
| 6. Other……….. | | |
| 7. Total | | |

**2.13** What is the terrain of your farm? (1= Flat, 2= Sloppy/Hilly) ………………………..

**2.3** What are the various crops that you grow? Please indicate in the table below.

| **2.3.**1Crop grown | **2.3.2** Do you grow this crop | **2.3.**3Land size grown (acres) | **2.3.**4Yield in the last **YEAR** | **2.3.5 Motive: (**1-Subsistence 2=Commercial 3= | **2.3.6** Years of |
|---|---|---|---|---|---|

| | (1=Yes 0=No) | | (Kg) | (Both subsistence and commercial) 4= Other... | Growing this crop |
|---|---|---|---|---|---|
| 1. Maize | | | | | |
| 2. Beans | | | | | |
| 3. Cowpeas | | | | | |
| 4. Pigeon peas | | | | | |
| 5. Millet | | | | | |
| 6. Sorghum | | | | | |
| 7. green grams | | | | | |
| 8. Vegetables | | | | | |
| 9.Other specify……….. | | | | | |

2.3.2 How many years do you have of farming experience? ................

**2.4** Do you have access to these inputs and equipment required in farming?

| | **2.4.1 Do you have access to these farm inputs? 1=Yes or 2=No** | **2.4.2 If not what are the various reasons. 1= lack of finances, 2=Poor input markets, 3= other** | **Cost per annum** |
|---|---|---|---|
| 1. Inorganic fertilizers | | | |
| 2. Organic Fertilizers | | | |
| 3. Improved seeds | | | |
| 4. Pesticides | | | |
| 5. Herbicides | | | |
| 6. Farm equipment eg hand hoes, pangas, ploughs etc | | | |

| | | | |
|---|---|---|---|
| 7. other specify | | | |

**SECTION C: Awareness of Climate variability and adaptation**

3.1 To what extent do you agree with the statements below on climate change over the past 20 years?

| | Do you agree with the following statements: 1=Yes 2=No |
|---|---|
| The number of rainy days has reduced | |
| Increased dry spells | |
| Frequent drought | |
| Frequent Floods | |
| New diseases for crops have emerged | |
| The rate of germination failure has increased | |

**3.2** Have you been exposed to various climate shocks and to what extent has it affected your crop (sorghum) in the last 10 years?

| | **3.2.1** Have you been exposed to these climate shocks? 1=yes 0=No | **3.2.2** If yes what was the frequency/ how many times in the past 10 yrs. | **3.2.3** If yes, how many times was your **CROP** affected by the shock over the last 10yrs |
|---|---|---|---|
| Flood | | | |
| Drought | | | |
| Erratic | | | |
| Hailstorm | | | |
| Other (specify) | | | |

**3.3** If yes 'above how do you cope and prevent these shocks from affecting your sorghum crops? Please use the codes below to fill in the table.

| | **3.3.1** How do you prevent these shocks from affecting your **CROPS**? **CODES** **1**=Nothing is done, **2=**Planting trees, **3**=Irrigation, **4=**Drought tolerant varieties, **5=**Change crop type, **6=**Diversification, **7=**Soil conservation techniques, **8=**Change cropping dates, **9=**Change land area, **10=** Guard fields when crops mature, **11=**Other (specify*)* |
|---|---|
| Flood | |
| Drought | |
| unpredictable rainfall | |
| Hailstorm | |
| Other (specify) | |

SECTION D: AWARENESS, ACCESS AND USE OF AGROMETEOROLOGICAL INFORMATION SERVICES

4.1 Have you received information about climate weather forecasts? 1= Yes { }, 2= No { }

4.1.2 If yes, through which sources do you access this information? …………… (1 = Television, 2 = Extension Officers, 3 = Newspapers, 4 = Cell Phone, 5 = Radio, 6 = Friends/Relatives, 7 = Peer Farmers, 8 = Internet, 9 = Baraza Meetings, 10 = Printed Materials, 11 = Village Leaders, 12 = Social Events, 13 = Religious Organizations, 14 = Other (please specify))

| | **4.1.3 Are you informed about the following weather forecasts? 1=yes 0=no** | **4.1.4 If yes, which pathway are you receiving the information? Codes:** 1=phone calling, 2=radio call-in, 3=radio broadcast 4=sms, | **4.1.5 Which is your preferred source of access? Codes:** 1=television, 2=extension officers, 3=newspapers, 4=cell phone, 5=radio, 6=friends/relatives, 7=peer farmers, 8=internet, 9=Baraza meetings, 10=printed materials, 11=village leaders, |
|---|---|---|---|

| | | | |
|---|---|---|---|
| | | 6=face to face individual, 7=face to face group, 8=audio-visual, 9=newspaper, 10=poster, 11=fliers, 12=online, 13=graphs, 14=other (specify) | 12=social events, 13=religious organizations, 14=other (specify) |
| Seasonal forecast for the start of the rainy season | | | |
| Forecasts for extreme weather events (such as very heavy rains, landslides, floods, and strong winds) | | | |
| Daily weather forecast (including predictions for rainfall, temperature, etc., for today or the next 2-3 days) | | | |
| Weekly weather forecasts (covering the next 7 days, including predictions for rainfall, temperature, clouds, etc.) | | | |
| Monthly weather forecast (including predictions for | | | |

| | | | |
|---|---|---|---|
| rainfall, temperature, etc.)<br>Long-term climate forecast (covering trends in climate variability over an extended period) | | | |
| Indigenous forecast (encompassing traditional knowledge and empirical observations) | | | |

**4.2** Is the climate information you receive accompanied by agronomic advice? Please fill in the table below using the provided codes.

| | **4.2.1 Is the climate information received accompanied with agronomic advice** 1=yes 0=no | **4.2.2 If yes, tell us which advice? Use CODES below** | 4.2.**3 If yes, how will you rate the usefulness of the service to inform your farm decisions and livelihood?** 1=not useful 2=small extent 3=medium extent 4=large extent 5=very large extent |
|---|---|---|---|
| Seasonal forecast for the start of the rainy season | | | |
| Forecasts for extreme weather events (such as very heavy rains, landslides, floods, and strong winds) | | | |

| | | | |
|---|---|---|---|
| Daily weather forecast (including predictions for rainfall, temperature, etc., for today or the next 2-3 days) | | | |
| Weekly weather forecasts (covering the next 7 days, including predictions for rainfall, temperature, clouds, etc.) | | | |
| Monthly weather forecast (including predictions for rainfall, temperature, etc.) | | | |
| Long-term climate forecast (covering trends in climate variability over an extended period) | | | |
| Indigenous forecast (encompassing traditional knowledge and empirical observations) | | | |

**Code for agronomic advice**: 1=Introduce new crops/varieties, 2=Plant early maturing varieties, 3=Start improved irrigation, 4=Improved drainage, 5=Introduce crop cover, 6=Introduce mulching, 7=Terraces, 8=Mechanized farming, 9=Early land preparation, 10=Early planting, 11=Late planting, 12=Use of chemical fertilizers, 13=Use of manure, 14=Use of pesticides/herbicides, 15=Agroforestry 16=Plant drought-resistant varieties 17=livestock off take 18=Herd splitting and migration 19=Mass vaccination/deworming 20=Breed improvement 20=Activate disease surveillance 21=Rangeland reseeding 22=Activate flood evacuation plans 23=Engage in alternative livelihood 24=Other (specify).

4.3 If you have access to agrometeorological information services, do you trust their accuracy and reliability? 1= Yes 2= No …….

4.3.1 If yes, to what extent do you trust in the information received on the following?

| | 1=not at all<br>2=small extent 3=medium extent 4=large extent 5=very large extent |
|---|---|
| Seasonal forecast for the beginning of the rainy season | |
| Forecast for severe weather events (such as intense rainfall, landslides, floods, or strong winds) | |
| Daily weather forecast (covering rainfall, temperature, etc., for today or the next 2-3 days) | |
| Weekly weather forecasts (covering rainfall, temperature, clouds, etc., for the upcoming 7 days) | |
| Monthly weather forecast (including rainfall, temperature, etc.) | |
| Long-term climate forecast (indicating trends and patterns in climate variability over an extended period) | |
| Indigenous forecast (based on traditional knowledge and empirical observations) | |

**4.3.2** If you do not trust the agrometeorological information services, please explain the reasons **(1=not accurate, 2=not familiar with the forecast, 3=complicated to understand, 4= other (specify)…………)**

**4.3.3** If you receive agrometeorological information, do you use it to guide your farming decisions? **1= Yes { } 2= No { }………….**

**4.3.4:** If you do not use the agrometeorological information, please explain the reasons.

(1= difficulty understanding the technical terms used in the forecasts, 2=does not understand the language used 3=not accompanied with advice 4=did not trust the reliability of the information 5=-other (specify)………)

**4.4** If you use climate information services for farm decision-making, please indicate the changes you have made in your farm management and livelihood by completing the table below:

| | Forecast of an extreme event (e.g: heavy rains, storm, dry spell, strong winds, other) 1=yes 0=No | 4.4.2 Forecast of the start of the rains (onset) 1=yes 0=No | 4.4.3 Forecast of the weather for today and/or next 2-3 days 1=yes 0=No | 4.4.4 Weekly weather forecast 1=yes 0=No | 4.4.5 Forecast of the rains for the following month 1=yes 0=No | 4.4.6 Long-term climate forecast 1=yes 0=No | 4.4.7 Indigenous climate forecast 1=yes 0=No |
|---|---|---|---|---|---|---|---|
| Timing of land preparation | | | | | | | |
| Timing of planting | | | | | | | |
| Distribution of land among | | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| different crops | | | | | | | |
| Selection of planting locations | | | | | | | |
| Choice of crop varieties to plant | | | | | | | |
| Change in crop type or variety | | | | | | | |
| Timing of fertilizer application | | | | | | | |
| Use of manure | | | | | | | |
| Timing of weeding | | | | | | | |
| Timing of harvesting | | | | | | | |
| Timing of crop sales | | | | | | | |

**SECTION E: INSTITUTIONAL AND INCOME INFORMATION**

**5.1** Do you belong to any group? Fill in the table below

| **Type of group** | **5.1.1 Group member** *(1=yes,* **0=no)** | **5.1.2=formal 2=informal** | ***5.1.3 If yes,*** **duration of membership in (years)** | **5.1.4 Which services are offered by the group (1=credit services, 2=marketing information, 3= marketing of produce 4=Climate information, 5= input purchase, 6=Agronomic advice 7=other, specify……………… …….)** | **5.1.5 Have you frequently participated in groups activities? 1= 1, 0 No.** |
|---|---|---|---|---|---|
| Farmers group | | | | | |
| Youth group | | | | | |
| Women group | | | | | |
| Men group | | | | | |
| Religious group | | | | | |
| SACCO/credit groups | | | | | |
| Environmental group | | | | | |
| Another group [specify] | | | | | |

**5.1.1** Have you received extension services in the past 12 months? **1**= Yes **0**= No

**5.1.2** Which organizations provided the extension services? **1**=Government of Kenya, **2**=NGOs, **3**=Private Organisations, **4**= Agro dealer, **5**= other

**5.1.3** Through which channel were the extension services provided?**1**= Phone call, **2**= field schools, **3**= home visits, **4**= other

**5.1.4** What were the terms for the extension services? **1**= Free, **2**= Paid, **3**= Other

**5.1.5** How frequently did the extension services occur? **1**=after every **3** Season, **2**= once per month, months, **3**= twice a year, 4= once per year.

**5.1.6** Do you have access to credit facilities? **1**= Yes **0**= No

**5.1.7** If yes, what was the source of the credit received? **1**= cooperative bank, **2**= Agricultural finance cooperative **3**= SACCO, **4**=Development group, **5**=Money lender/shylock, **6**=relative/ friend/ neighbour, **7**= community based organisation, **8**= mobile money **9**= other specify

**5.1.8** What was the primary use of the credit? **1**= buy household food **2**= buy farm inputs, **3**= buy livestock, **4**= buy farmland, **5**= other

**5.1.9** What factors prevented you from accessing credit? (If 5.1.6 is 0 = No) Note if **5.6** is **0**= no. **1**= Lack of collateral, **2**= high-interest rates, 3=lengthy procedures, 4=no need, 5=unable to pay back, 6= other

**5.1.10** Do you have access to markets? Please provide details in the table below.

| | **Do you have access to markets 1= Yes, 0= No** | **Average in Distance Kilometres** | **What type of roads. 1= tarmac, 2= murram, 3= Earth** | **What is the means of transport 1= Public means, 2= Private car, 3= Motorbike, 4= bicycle, 5= walking, 6= other** |
|---|---|---|---|---|
| 1. Input Markets | | | | |
| 2. Crop produce market for | | | | |
| 3. Livestock and livestock products market | | | | |

**5.11** To capture the average monthly household income, please provide the following details in the table below

| Income source | **5.12.1** Amount earned (Ksh) | **5.12.2** Who controls the income from this source? (1= HH head 2= spouse 3= other specify) |
|---|---|---|
| Farming | | |
| Off-farm activities (farm activities on other holders‘ farm etc) | | |
| Non-farming activities (e.g owned business, handicraft, carpenter, charcoal etc) | | |
| Remittances and gifts | | |
| Formal employment | | |
| Other income sources, specify……………. | | |

**Appendix F**: Research Permit

REPUBLIC OF KENYA

NACOSTI

NATIONAL COMMISSION FOR
SCIENCE,TECHNOLOGY & INNOVATION

Ref No: **957508**

Date of Issue: **09/January/2023**

**RESEARCH LICENSE**

**This is to Certify that Mr.. Godfrey Atsiaya Atsiaya of Egerton University, has been licensed to conduct research as per the provision of the Science, Technology and Innovation Act, 2013 (Rev.2014) in Busia on the topic: AGROMETEOROLOGICAL INFORMATION AND ADAPTATION TO CLIMATE VARIABILITY AMONG SMALLHOLDER SORGHUM FARMERS IN BUSIA COUNTY, KENYA for the period ending : 09/January/2024.**

License No: **NACOSTI/P/23/22972**

**957508**

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INNOVATION

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**See overleaf for conditions**

**Appendix G:** Ethical Clearance

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EGERTON

**EGERTON UNIVERSITY INSTITUTIONAL SCIENTIFIC AND ETHICS REVIEW COMMITTEE**

**EU/RE/DVC/009**
***Approval No. EUISERC/APP/209/2022*** ***19th December*, 2022**

Godfrey Obwina Atsiaya
Address: P.O Box 536- 20115
Egerton
Telephone: +254722754917
E-mail: goddyatsiaya@gmail.com

Dear Godfrey,

**RE: ETHICAL APPROVAL: AGROMETEOROLOGICAL INFORMATION AND ADAPTATION TO CLIMATE VARIABILITY AMONG SMALLHOLDER SORGHUM FARMERS IN BUSIA COUNTY, KENYA**

This is to inform you that ***Egerton University Institutional Scientific and Ethics Review Committee*** has reviewed and approved your above research proposal. Your application approval number is ***EUISERC/APP/209/2022.*** The approval period is ***19th December, 2022 –20th December, 2023.***

This approval is subject to compliance with the following requirements;

i. Only approved documents including (informed consents, study instruments, MTA) will be used.
ii. All changes including (amendments, deviations, and violations) are submitted for review and approval by ***Egerton University Institutional Scientific and Ethics Review Committee.***
iii. Death and life-threatening problems and serious adverse events or unexpected adverse events whether related or unrelated to the study must be reported to ***Egerton University Institutional Scientific and Ethics Review Committee*** within 72 hours of notification
iv. Any changes, anticipated or otherwise that may increase the risks or affected safety or welfare of study participants and others or affect the integrity of the research must be reported to ***Egerton University Institutional Scientific and Ethics Review Committee*** within 72 hours.

***"Transforming Lives through Quality Education"***

v. Clearance for Material Transfer of biological specimens must be obtained from relevant institutions.
vi. Submission of a request for renewal of approval at least 60 days prior to expiry of the approval period. Attach a comprehensive progress report to support the renewal.
vii. Submission of an executive summary report within 90 days upon completion of the study to ***Egerton University Institutional Scientific and Ethics Review Committee***.

Prior to commencing your study, you will be expected to obtain a research license from National Commission for Science, Technology and Innovation (NACOSTI) https://oris.nacosti.go.ke and also obtain other clearances needed.

Yours sincerely.

EGERTON UNIVERSITY
Date. 19/12/2022
RESEARCH ETHICS

Prof. R. Ngure
**CHAIRMAN, EGERTON UNIVERSITY INSTITUTIONAL SCIENTIFIC AND ETHICS REVIEW CTTEE**
*RMN/BK/*

*"Transforming Lives through Quality Education"*

**Appendix H:** Publications

*Natural Resources Conservation and Research (2023) Volume 6 Issue 2*
doi: 10.24294/nrcr.v6i2.2290

ORIGINAL RESEARCH ARTICLE

# Composite effect of adaptation to climate variability, agrometeorological information, and socioeconomic and institutional factors on agricultural productivity in Kenya

**Godfrey Obwina Atsiaya[1,*], Eric Obedy Gido[1], Kenneth Waluse Sibiko[2], Joseph Jabu Mbudzya[1]**

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## ABSTRACT

Climate variability has adversely affected agriculture and adaptation strategies are significant in enhancing resilience hence ensuring food security. Agrometeorological services are essential in decision-making and developing farmers' specific adaptive capacities mainly when variability affect agricultural productivity. This study focuses on the composite effect of adaptation to climate variability, agrometeorological information, socioeconomic and institutional factors on agricultural productivity in Kenya. Multi-stage sampling technique was used to obtain a sample size of 384 sorghum farmers. The study used an endogenous switching regression model to control for the selection problem arising from adaptation to climate variability on agricultural productivity. Results indicate that extension contacts and education level were positively significant among adapters of climate variability. Additionally, the proportion of income allocated for farming was positively significant among non-adapters. On the other hand, access to credit, gender and age of decision makers were negatively significant among adapters of climate variability. Similarly, age was negatively significant among non-adapters of climate variability. Overall, adapters to climate variability had higher sorghum output than non-adapters. This study recommends that policymakers and other key stakeholders could increase the number of extension contacts and promote education to farmers so that they can access agrometeorological information, hence adaptation to climate variability.

***Keywords:*** adaptation strategies; agricultural productivity; Busia County; climate variability; endogenous switching regression

**ARTICLE INFO**

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## 1. Introduction

Agriculture is the mainstay of many economies, contributing to food security and the employment of rural households, especially in sub-saharan Africa (SSA)[1]. The SSA region hosts about 950 million people, about 13% of the global population. The population is expected to increase to about 2.1 billion people in 2050[2]. Therefore, the demand for food keeps rising, underscoring the agricultural sector's significance in contributing to food security[3]. The agricultural sector also directly or indirectly contributes significantly to many SSA economies. On average, agriculture contributes 15% of total gross domestic product (GDP), ranging from 1.9% in botswana with the highest, 57.4% in sierra leone[4]. The agricultural sector offers employment to more than half of the total labour force in SSA. Among the rural population, it is a source of livelihood for many small-scale producers. The small-scale farmers constitute

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Reviewing editor:
Manuel Tejada Moral, University of Seville, Seville, Spain

Additional information is available at the end of the article

SOIL & CROP SCIENCES | RESEARCH ARTICLE

# Uptake of climate-smart agricultural practices among smallholder sorghum farmers in Busia County, Kenya

Godfrey Obwina Atsiaya[1*], Eric Obedy Gido[1] and Kenneth Waluse Sibiko[2]

**Abstract:** With global climatic shifts and increase in greenhouse gases (GHG) emissions, agriculture is a contributor, but it is largely affected by the effects, particularly affecting the smallholder farmers. Climate-smart agricultural (CSA) practices provide the best solution for adapting to climate change and variability. Moreover, some CSA practices act as carbon sinks, thereby helping reduce GHG build-up in the atmosphere. These practices may include conservation agriculture, agroforestry, water conservation, use of tolerant varieties and breeds, as well as the use of risk insurance. Despite the highlighted benefits, the uptake of CSA practices among smallholder sorghum farmers in Busia county is still low. From the foregoing, this study sought to evaluate factors affecting the level of uptake of CSA practices among smallholder sorghum farmers in Busia County. With the aid of a semi-structured questionnaire, primary data were collected from 423 smallholder sorghum farmers selected through multistage sampling technique. Data were analysed using the standard Poisson regression model. The average number of CSA practices adopted by sorghum farmers in the past one year was two, with a minimum of zero and a maximum of thirteen. Age of the farmer, farming experience, ownership and the proportion of land under farming, access to credit, frequency of receiving agrometeorological information, trust in the information, number of farmers' trainings attended, and exposure to climate shocks, significantly influenced CSA practices uptake level. Findings give insights on provision of

## ABOUT THE AUTHORS

Godfrey Obwina Atsiaya

Godfrey Obwina Atsiaya is a PhD Candidate in Agricultural economics at Egerton University. He has over five years of experience in agriculture-based research, with areas of interest spanning from, climate-smart technologies, role of market innovation in inclusive and sustainable smallholder agriculture, transitioning agri-food systems in sub-Sahara Africa, agri-value chains development, sustainable rural development and livelihoods assessment. Atsiaya has done extensive work on climate variability adaptation, mitigation and adoption of technologies by smallholder farmers.

Eric Obedy Gido is a Lecturer in the Department of Agricultural Economics and Agribusiness Management from Egerton University. He holds a PhD in Agricultural Economics and specializes in production Economics and Agricultural Markets.

Kenneth Waluse Sibiko is a Postdoctoral Socialscientist at The Alliance of Bioversity International and CIAT. He holds a PhD in Agribusiness Management and specializes in consumer behaviour and willingness to pay.

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# Factors influencing access to agrometeorological information among sorghum farmers: Empirical evidence among sorghum farmers in Busia County, Kenya

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## ABSTRACT

An increase in climatic shocks resulting from climate change is indeed affecting agricultural productivity among smallholder farmers. Agrometeorological information plays a significant role in helping smallholder farmers with the necessary information to overcome some of the shocks due to climate changes, thereby improving agricultural productivity and incomes. However, access to agrometeorological information among smallholder farmers has been a challenge despite the available agrometeorological information on various platforms and yet this is essential in managing climate change. This study aimed to understand the factors influencing access to agrometeorological information among sorghum farmers in Busia county, Kenya. Primary data collected from 423 smallholder sorghum farmers were used. Using a structured questionnaire and a well-trained team of research assistants, data were collected using a multistage sampling technique. Data were analysed using a binary logistic model in STATA 16 software. The findings revealed that 90% of the smallholder farmers had been exposed to climatic shocks such as droughts and erratic rainfall. The econometric model showed that farmers' location, age, farming experience, radio ownership, access to internet services and credit facilities influenced access to agrometeorological information. The study recommends that improving infrastructure such as roads, electricity, and telecommunication networks is necessary for improving access to agrometeorological information. Moreover, relaying reliable information by agro-met advisors is vital in strengthening farmers' trust, which is essential in accessing agrometeorological information.

Keywords: Agrometeorological information, Binary logistic model, Busia County, Climate change, Kenya, Sorghum farmers

## RÉSUMÉ

Une augmentation des chocs climatiques résultant du changement climatique affecte en effet la productivité agricole des petits exploitants agricoles. L'information agrométéorologique joue un rôle significatif en aidant les petits agriculteurs avec les informations nécessaires pour surmonter certains de ces chocs dus aux changements climatiques, améliorant ainsi la productivité agricole et les revenus. Cependant, l'accès à l'information agrométéorologique parmi les petits exploitants reste un défi malgré la disponibilité de l'information agrométéorologique sur diverses plateformes, et pourtant cela est essentiel dans la gestion du changement climatique. Cette étude visait à comprendre les facteurs influençant l'accès à l'information agrométéorologique

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