INFLUENCE OF WEATHER AND CLIMATE INFORMATION SERVICES AND CLIMATE-SMART TECHNOLOGIES ON BEAN PRODUCTIVITY AND HOUSEHOLD RESILIENCE AMONG SMALLHOLDER FARMERS IN HOMA BAY TOWN SUB-COUNTY, KENYA

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A Thesis Submitted in Partial Fulfilment of the Requirements for the Degree of Master of Science in Climate Smart Agriculture of Murang'a University of Technology

August, 2026

DECLARATION

Student Declaration

I hereby declare that this Thesis is my original work and to the best of my knowledge has not been presented for a degree award in this or any other university. I understand what plagiarism is and I am aware of the University's policy in this regard. I understand that any false claim in respect of this work shall result in disciplinary action in accordance with the University Anti-Plagiarism Policy.

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Supervisors' Approval

The undersigned certify that they have read and hereby recommended for acceptance of Murang'a University of Technology a thesis entitled, "**Influence of Weather and Climate Information Services and Climate-Smart Technologies on Bean Productivity and Household Resilience among Smallholder Farmers in Homa Bay Town Sub-County, Kenya".**

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DEDICATION

I dedicate this work to my loving parents, Mr Alex Lusigi and Mrs Everlyne Lusigi, for their unwavering support, encouragement and prayers, which have been my greatest source of strength. I also dedicate this work to my sisters Eulentine and Doris, Brothers Innocent and Clide and my husband, Mr Felix Okoth, for always believing in me and inspiring me to keep moving forward. I am deeply grateful.

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ABSTRACT

Climate change and variability continue to constrain smallholder agricultural productivity and resilience in sub-Saharan Africa. Weather and Climate Information Services (WCIS) and Climate-Smart Technologies (CSTs) are promoted as primary adaptation strategies. Yet, there is no comprehensive empirical evidence on the combined effects of these strategies on the productivity and resilience of common bean farmers. Common bean was selected because it promotes food security, household nutrition and income among smallholder farmers in Kenya, including Homa Bay Town-Sub-County; however, it is highly sensitive to climate variability. This study broadly assessed how WCIS affects the adoption of CSTs and its implications for common bean productivity and the resilience of farmers in Homa Bay County, Kenya. A mixed-methods design that is quasi-experimental and a cross-sectional survey was adopted, involving a sample size of 157 bean farmers previously subjected to WCIS training conducted over a defined period before this study, after which no further training was conducted. A quasi-experimental design was used to compare CST-adopters (n=25) and non-adopters of CST (n=25) with the remaining 107 farmers involved in a cross-sectional survey. The structured questionnaires and observation checklists were used to obtain data, which were analyzed through descriptive statistics, log-linear regression and the Structural Equation Model (SEM). All the respondents reported access to WCIS, and 59.2% of the farmers reported that key farm decisions were made using the WCIS and that CSTs were adopted because of the WCIS. The most commonly adopted CSTs were intercropping (54.1%) and organic manure application (49.7%). Farmers' adoption of weather-informed farming practices was high, with 96.2% changing planting dates and 95.5% using early-maturing bean varieties. Nearly 84.7% of farmers reported higher common bean production, and 78.3% reported lower losses. The intensity of CST adoption was significantly associated with higher common bean productivity, with mean yields ranging from 135.8 kg $acre^{-1}$ for non-adopters to 348.2 kg $acre^{-1}$ for adopters. Log-linear regression analysis revealed that for every increment in the level of adoption of CST, common bean yields increased significantly by 41.8% ($\beta = 0.349$, $P \leq 0.003$). The results from SEM showed that the adoption of CST was significantly affected by WCIS ($\beta = 0.447$, $P \leq 0.001$) and that common bean productivity also had a significant positive effect on household resilience ($\beta = 0.341$, $P \leq 0.001$). Unreliable weather forecasts, insufficient information and lack of confidence in providers were the most common obstacles. The present study found that the use of reliable WCIS coupled with CSTs could significantly boost common bean productivity and enhance smallholders' resilience to climate change. Based on these findings, the study recommends strengthening access to timely and reliable weather and climate information services, alongside promoting the adoption of climate-smart technologies through enhanced extension services, farmer training, and supportive policy frameworks.

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ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of Variance
CGIAR	Consultative Group on International Agricultural Research
CIAT	International Center for Tropical Agriculture
CIS	Climate Information Services
CSATs	Climate Smart Agriculture Technologies
CSTs	Climate Smart Technologies
DOI	Diffusion of Innovations
FAO	Food and Agriculture Organization
KALRO	Kenya Agricultural & Livestock Research Organization
KMD	Kenya Meteorological Department
MUT-ISERC	Murang'a University of Technology Institutional Scientific and Ethics Review Committee
NACOSTI	National Commission for Science, Technology and Innovation
OLS	Ordinary Least Squares
SEM	Structural Equation Model
SSA	Sub-Saharan Africa
STATA	Statistical and Data Analysis
WCIS	Weather and Climate Information Services
WIPs	Weather-informed Practices

DEFINITION OF OPERATIONAL TERMS

Climate-Smart Technologies (CSTs)- Refers to the set of agricultural practices adopted by farmers to improve productivity and enhance resilience to climate variability. CSTs are operationalized through adoption intensity, measured by the number of climate-smart practices implemented by a farmer.

Weather and Climate Information Services (WCIS)- Refers to the provision and use of weather forecasts and climate advisories that support farm-level decision-making. In this study, WCIS is operationalized based on farmers' access to, frequency of use, and application of information in agricultural decision-making.

Weather-Informed Practices (WIPs)- Refer to farm Management decisions guided by weather and climate information. In this study, WIPs are measured by the extent to which farmers adjust practices such as planting time, crop selection, and input use based on climate information.

Adoption Intensity- Refers to the degree to which a farmer implements multiple climate-smart technologies. It was measured as the total number of CSTs adopted by an individual farmer.

Common Bean Productivity- Refers to the output of common beans per unit area under farm conditions. In this study, it is measured using yield levels (kilograms per acre) reported by farmers.

Household Resilience- Refers to the capacity of a farming household to anticipate, cope with, and recover from climate-related shocks. In this study, it is operationalized using a composite index capturing production stability, food security, and adaptive capacity.

Smallholder Farmers- Refers to farmers cultivating relatively small land holdings (typically less than 2 hectares), relying primarily on family labour and rain-fed agriculture for subsistence and income generation.

Climate Variability- Refers to fluctuations in weather patterns, including changes in rainfall and temperature, that affect agricultural production over time.

CHAPTER ONE
INTRODUCTION

1.1 Background Information

Agriculture remains a fundamental sector for global food security, livelihood and economic development, particularly in developing countries where millions depend on agriculture for income and employment. Global warming and weather changes, including warmer climates, unpredictable rainfall, floods, droughts, and pest and disease outbreaks, are, however, becoming a growing menace in the sector. These constraints are particularly significant when it comes to the production of common beans that are highly sensitive to the changes in climatic conditions during flowering, pod development, and maturation (FAO, 2021; World Bank, 2022). In response, the research community has been advancing and promoting climate-smart agriculture technologies (CSATs) and using Weather and Climate Information Services (WCIS) to strengthen and adapt farming systems (Nyadzi *et al*. (2021).

Common bean (*Phaseolus vulgaris* L) is a food crop that also provides income to millions of smallholder farmers in Sub-Saharan Africa (SSA). Indeed, SSA is the largest producer and consumer of common beans, with major production recorded in East Africa (Buruchara *et al.,* 2020; Katungi *et al.,* 2021; Kimani and Otsyula, 2022). Beans are a crucial source of food because they offer principally protein and other vital micronutrients, primarily to low-income families. Despite their importance, the average yields of common beans in Kenya remain below the global potential, indicating a significant yield gap. This gap has been largely attributed to recurrent drought, alongside other biotic and abiotic stresses such as pests, diseases, and declining soil fertility (FAO,2021; Alliance Bioversity International & CIAT, 2021). Despite this importance, uncertainties of rainfall, recurrence of droughts, lack of soil fertility, infestation of pests, and heat stresses limit bean production (Ampaire *et al.,* 2020). Research has shown that services provided by climatologists, such as localized forecasts, personalized advisories, and early warning, may be used to increase productivity by improving the decisions and choices that farmers make about when to plant, the kind of crop to plant and how to use the available resources (Roudier *et al.,* 2023). Nevertheless, there is still a limited extent to which these services can be

accessed and influence the practice of farmers, especially in the rural regions where socio-economic and institutional obstacles are observed (Nyadzi *et al.,* 2021).

In Kenya, Common beans are important not only in household nutrition, but also in generating income and food security of the country. Smallholder farmers in various agro-ecological regions extensively grow beans, and it is a significant part of their mixed-farming system (Alliance Bioversity International & CIAT, 2021). Nonetheless, the climate variability is limiting the production of common beans in most regions of the country through delayed rainfalls, reduced growing periods, and increased cases of pests and diseases (Karanja *et al.,* 2022). Such difficulties lead to unpredictable production and low agricultural earnings of smallholder farmers. In turn, national meteorological and agricultural organizations like the Kenya Meteorological Department (KMD) and Kenya Agricultural and Livestock Research Organization (KALRO) have intensified sharing of weather forecasts, climate advisory services and promotion of climate-smart agricultural technologies to facilitate making decisions in climate-sensitive farming (CGIAR, 2023). Irrespective of these efforts, unequal availability and utilization of the weather and climate information to the farmers in various parts of the country still exist.

The County Government of Homa Bay in western Kenya forms a great context for analyzing the connection between WCIS, the use of climate-smart technologies (CSTs), and agricultural productivity. The farming sector in the county is mostly rain-fed and hence extremely vulnerable to the rain pattern and temperature changes (Homa Bay County Government, 2023). Weather patterns such as seasonal ones have a substantial impact on the time of planting, how crops are managed, and their yields among smallholder farmers in the area (Homa Bay County Government, 2023). Over the last few years, the county government and development partners have presented weather and climate information platforms to enhance the access of farmers to localized weather advisories and seasonal forecasts (Homa Bay County Government, 2024). Such services offer advice on the planting dates, input management and pest control programs depending on the forecasted climatic conditions (Homa Bay County Government, 2024). Nevertheless, the literacy levels, infrastructure, digital access, and extension facilities are still some of the factors determining how the farmers access and use WCIS in the county (Homa Bay County Government, 2024).

To enhance climate resilience in the smallholder agricultural systems, it is important to understand how information on weather and climate affects the adoption of CSTs and agricultural productivity by farmers. Local contexts are of special importance in informing agricultural policies, extension policies, and climate adaptation schemes and programs that would enhance the productivity of bean-growing households and improve their livelihoods.

1.2 Problem Statement

Common bean production is one of the key livelihood activities of the smallholder farmers in Homa Bay Town Sub-County. Climate-related problems, such as unpredictable rainfall patterns, extended dry periods, floods, and pests and disease outbreaks, have, however, been negatively influencing bean productivity in the area (Homa Bay County Government, 2023; Mabhaudhi et *al.,* 2025). This has particularly been evident in such wards as Homa Bay *Arujo* and Homa Bay West, where weather conditions and soil properties continue to influence the production of beans (Maarifa Centre, 2023). In this study area, smallholder bean farmers use a blend of conventional and improved farming practices. Nevertheless, no empirical data exist on the performance of these practices during varying climatic conditions, especially when planting decisions, input application, and common bean productivity are in concern. Yet, although climate-smart technologies (CSTs) are encouraged as a means of adaptation, their impact on the productivity of common bean under on-farm conditions among Homa Bay Town Sub-County smallholder bean farmers has not been adequately studied (Kurgat et al., 2025; Muriithi *et al.,* 2024).

The WCIS provided are meant to facilitate the decision-making process at the farm level through providing weather forecasts and climate advisories that can be utilized to plan the agricultural activities. It is, however, not stated clearly the extent to which smallholder bean farmers in the region under study obtain and utilize such information and how this can affect their choice of adopting CSTs (Nyoni *et al.,*2024; Mboya et *al.,* 2024). This leaves a knowledge gap regarding the significance of climate information in influencing adaptive behavior and bean productivity among smallholder bean farmers.

Moreover, although climate-informed agriculture is advocated to increase productivity and resilience, it is not thoroughly studied in the local context in terms of its role in

promoting common bean productivity and household climate risk resilience in smallholder bean farmers (Kurgat *et al.,* 2025). Without such evidence, there is a constraint to the capacity of smallholder bean farmers, extension services, and policymakers to make informed decisions and come up with context-specific interventions.

Therefore, the challenge addressed in this study is the lack of clear, context-specific empirical evidence or data on how WCIS influences the adoption of CSTs, common bean productivity and household resilience among smallholder bean farmers in Homa Bay Town Sub-County.

1.3 Research Objectives

1.3.1 General Objective

To contribute to improved common bean productivity and household resilience by assessing the influence of weather and climate information services and climate-smart technologies among smallholder bean farmers in Homa Bay Town Sub-County.

1.3.2 Specific Objectives

1. To evaluate the effects of climate-smart technologies (CST) on the productivity of common beans under on-farm conditions among bean farmers.
2. To assess how the use of weather and climate information services (WCIS) influences the adoption of climate-smart technologies among bean farmers.
3. To assess the contribution of weather-informed practices (WIPs) to the productivity of common bean among participating farmers.
4. To assess the contribution of weather-informed practices (WIPs) to household resilience to climate-related risks among the participating farmers.

1.4 Research Hypotheses

1. H_{01}: Climate-smart technologies (CSTs) have no significant effect on the productivity of common beans among smallholder farmers.
2. $H_{02:}$ The use of weather and climate information services (WCIS) has no significant effect on the adoption of climate-smart technologies among common bean farmers.
3. H_{03}: Weather-informed practices (WIPs) have no significant effect on the productivity of common beans among participating farmers.

4. H_{04}: Weather-informed practices (WIPs) have no significant effect on household resilience to climate-related risks among participating farmers.

1.5 Scope and Limitations

The study was conducted in Homa Bay Town Sub-County, which is one of the major bean-producing areas in Homa Bay County. There are four sub-county wards, namely Homa Bay Central, Homa Bay Arujo, Homa Bay West and Homa Bay East, with varying climatic and soil conditions impacting bean production in the sub-county (Homa Bay County Government, 2023). The study focused on evaluating the effects of Weather and Climate Information Services (WCIS) on the adoption of climate change technologies, production of beans and the resilience of farmers to climate risk. This study was carried out among smallholder bean farmers, who, in the context of this study, were farmers who farm relatively small plots (usually less than 2 hectares) and who use mainly family labor and rain-fed agriculture for both subsistence and income generation. Farmers qualified as smallholders if they met these criteria and were actively engaged in bean production within the study area during the reference period. The selected farmers also had exposure to WCIS training. It involved the use of quasi-experimental and survey methods to produce both quantitative and qualitative data. This study focused on data from the most recent two planting seasons, namely the long rains and short rains seasons preceding the survey period.

The study focused on smallholder bean farmers in Homa Bay Town Sub-County who had been exposed to Weather and Climate Information Services (WCIS) training. Therefore, the findings may not be fully generalizable to farmers without such exposure or to other regions with different agro-ecological and institutional conditions.

The sample size of 157 farmers, divided into two groups: a quasi-experimental group (n=50) and a cross-sectional survey sample (n=107), provided useful insights but may not have been sufficient to detect small but statistically significant effects, particularly in the regression analysis.

The quasi-experimental component relied partly on farmers' recall of past production and management practices, which may have introduced recall bias and affected the accuracy of historical yield estimates. In addition, data were collected over a limited

number of recent growing seasons, restricting the assessment of long-term impacts of climate-smart technologies (CST) and WCIS.

Furthermore, the cross-sectional nature of part of the data limited causal inference, and some variables were based on self-reported information, which may be subject to response bias. Differences in farm conditions, such as soil variability and seasonal weather fluctuations, may also have influenced the observed productivity outcomes.

1.6 Assumptions of the Study

The research was carried out with the realization that the smallholder bean farmers who had gone through the Weather and Climate Information Services (WCIS) training in the Homa Bay Town Sub-County had a fundamental understanding of the recommended practices and advice regarding the weather patterns. It was assumed that farmers would be able to reasonably recollect and document their bean production measures, input application and recorded yield results of the current and the previous two growing seasons, and meaningful comparisons could be made between CST adopters and non-adopters

The research was based on the perception that differences in production among bean farmers indicated some degree of difference in the use of climate-smart technologies and the utilization of weather and climate data among other farm-related attributes. Even though the sampled farmers had all been exposed to WCIS training, differences in access, interpretation and use of this information were more likely to have an impact on CST adoption decisions and future farming practices.

Lastly, it was the assumption of the study that the sample and the study period covered the normal bean production environments in Homa Bay Town Sub-County. The variables measured to evaluate productivity and resilience were to be suitable in capturing the reaction of farmers to climate-related risks in the local farming environment.

1.7 Contributions of the Thesis

This thesis has made a substantive contribution to the field of climate-smart agriculture by contributing empirical evidence of the contribution of weather and climate information services (WCIS) to the farm-level decision making processes of

smallholder common bean farmers in a real on-farm context. The study has contributed to the existing body of knowledge, as most of the literature has been directed towards staple cereals, and also represented an important gap in the field of climate adaptation research, since it offered knowledge of adaptation for legumes, specifically common beans

The thesis also helped to advance the link between WCIS use and the adoption of climate-smart technologies (CSTs), showing how climate information was used to impact or change farmers' management and behavior decisions. It also analysed the effect of weather-informed practices (WIPs) and their synergy in productivity and household vulnerability to climate risks. This integrated approach was more than a simple factor analysis because it considers the interactions of the information of the climate, agricultural practices, and socio-economic factors that affect agricultural production.

The thesis also offered context-specific information on the smallholder farming systems, taking into account the institutional and socio-economic determinants of access to, interpretation of, and use of climate information. It emphasized that the impact of the WCIS was not only related to the availability of information, but also its accessibility, usability and relevance to the needs of the farmers.

Overall, the thesis contributed to the understanding of climate-smart agriculture, as the combined effect of informed decision-making and climate adaptive practices was found to affect productivity and resilience better than interventions alone. It thus made both a theoretical and practical contribution, in strengthening integrated approaches to climate adaptation and in providing inputs into the design of more effective, farmer-focused climate information services and agricultural support systems.

1.8 Organization of the Thesis

This thesis was structured to present a logical progression from the research problem to the study findings and their implications within the context of climate-smart agriculture and smallholder bean production. It began with the background to the study, highlighting climate variability and the role of weather and climate information services in influencing farm-level decision-making, before examining how these services interacted with technology adoption, productivity, and resilience outcomes.

The first chapter presented the background to the study, statement of the problem, research objectives, and justification, while also outlining the significance, scope, limitations, and key assumptions of the research. The second chapter reviewed relevant literature on climate-smart technologies, weather and climate information services, weather-informed practices and their role on bean productivity and household resilience, and established the theoretical and conceptual foundations of the study.

The third chapter described the methodology, including the research design, study area, sampling procedures, data collection methods, and analytical techniques used to examine the relationships among WCIS, climate-smart technologies, and weather-informed practices. The fourth chapter presented and discussed the findings, focusing on WCIS use, adoption of climate-smart technologies and weather-informed practices, and their effects on productivity and risk reduction, while relating the results to existing literature.

The final chapter synthesized the findings by drawing conclusions and providing recommendations for improving the effectiveness and accessibility of climate information services, while also identifying limitations and areas for further research.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

This chapter reviewed literature on the effects of climate-smart technologies (CSTs) on common bean productivity, the influence of weather and climate information services (WCIS) on CST adoption, and the contribution of weather-informed practices (WIPs) to bean productivity and household resilience. It further examined the role of CSTs in bean production, identified gaps in existing empirical evidence, and presented the Diffusion of Innovations Theory and Resilience Theory that guided the study. The chapter concluded by presenting the conceptual framework linking WCIS, CST adoption, WIPs, productivity, resilience, and the relevant contextual factors influencing these relationships.

2.2 Effects of Climate-Smart Technologies on the Productivity of Common Beans Under on-farm conditions

Recent research also shows that common beans among smallholder farmers could be more productive using climate-smart technologies (CSTs). Some of the practices that can be used to increase yields and adaptation to climate variability include the use of better seed varieties, integrated soil fertility management, crop diversification, and conservation agriculture. As an example, the use of better varieties of beans and soil fertility methods boosted yields amongst smallholder farmers immensely in Kenya (Okelo *et al.,* 2022). On the same note, Mugwe *et al.* (2021) established that the combination of organic and inorganic fertilizers enhanced nutrients in the soil and bean yield in smallholder conditions. Moreover, Kurgat *et al.* (2020) found out that conservation agriculture interventions, such as minimum tillage and mulching, has been associated with increased crop yields and enhanced moisture retention in rain-fed agriculture. Additional results by Mutenje *et al.* (2021) indicate that the adoption of multiple climate-smart practices results in greater productivity gains as opposed to single technologies. Similarly, Ng'ombe *et al.* (2020) established that combined soil and water management systems were very useful in enhancing yields and agro-resilience of smallholder systems. The findings indicate that CSTs play a very important role in enhancing the productivity of beans especially in regions where rainfall is erratic like in Homa Bay County.

Nonetheless, there are still some gaps in the literature available. To begin with, most studies are grounded in individual technologies as opposed to evaluating the overall impacts of multiple CSTs as implemented by farmers. Second, most researchers use experimental or controlled conditions, and these conditions do not represent the real on-farm conditions where farmers are subjected to various socio-economic and environmental limitations. Third, the empirical evidence comparing the productivity outcomes between the adopters and non-adopters of CST is not very strong, so it is hard to find the causal effects. Fourth, not many studies are location-specific in the Homa Bay Town Sub-County, although it is very susceptible to climate variability and diminishing soil fertility. Also, the socio-economic factors that can affect the results of adoption and productivity are not always considered in the analysis (Manda *et al.,* 2020; Wainaina *et al.,* 2021; Mutenje *et al.,* 2021).

The research filled these gaps through conducting a quasi-experimental study to compare the productivity of common beans between those who had adopted CSTs and those who had not adopted CSTs in Homa Bay Town Sub-County. The analysis employed on-farm information of smallholder farmers to represent actual production. It incorporates the effects of several CSTs as opposed to single practices. It also incorporates the socio-economic and institutional factors to provide a more appropriate explanation of productivity differences. In such a way, the paper offers strong evidence of the usefulness of CSTs to enhance the yield of beans, which can be used to inform farmers, extension services, and policymakers (Okelo *et al.,* 2022; Wainaina *et al.,* 2021).

2.3 Influence of Weather and Climate Information Services on the Adoption of Climate-Smart Technologies

Empirical studies show that the provision of weather and climate information services (WCIS) and practices (WIPs) play an important role in improving agricultural production and farmers' ability to respond to weather and climate risks (Amwata *et al.,*2018). The services producing this information and data help farmers make decisions about important farm operations like planting dates, agro-investments (consumption and storage) and water use. Research in sub-Saharan Africa shows that by providing useful climate information, access to climate information enhances crop performance and limits exposure to climate shocks by helping farmers plan their

activities in response to the expected climate conditions (Ngigi & Muange, 2022; Clarkson *et al.,* 2022). For example, farmers who received climate advisories were more likely to adjust their planting dates, soil moisture management and decrease climate risk losses, which resulted in enhanced production stability (Amwata *et al.,*2018; Ajwang *et al.,* 2024; Abidoye *et al.,* 2025).

Despite this growing evidence, the research conducted so far has been mainly focused on the staple cereals (maize and wheat) and not on legumes (common beans). This results in a large information gap, due to the different responses of beans to various climatic stresses or variations in temperature, especially drought. Therefore, results of cereal-based studies cannot be easily applied to bean production systems. Moreover, most of the studies focus on quantification of overall productivity effects, but not on quantifying climate resilience outcomes that are relevant to smallholder farmers in a climate uncertainty context, like yield stability, risk reduction (Ngigi & Muange, 2022; Ajwang et al., 2024).

Moreover, socio-economic and institutional factors can impact the weather-informed practices, for example, farmer access to extension, education, and farmers' ability to access and interpret climate information. Evidence of a lack of advisory services and/or recommendations for local contexts is needed if the information is to be useful in helping to secure productivity growth or sustainability (Clarkson *et al.,* 2022; Abidoye *et al.,* 2025). Farm-level evidence of the interaction of these factors to outcomes of the WIPs, however, is lacking in the study, with particular emphasis on the Homa Bay Town Sub-County. This study aims to tackle these gaps by assessing the impact of weather-informed practices on bean productivity and resilience of household livelihoods in real on-farm situations, and by accounting for socio-economic and institutional factors influencing the outcomes of these practices.

2.4 Contribution of Weather and Climate Informed Practices to Bean Productivity and Farmers' Resilience

Empirical evidence is accumulating to indicate that weather-informed practices (WIPs) can have a significant effect on the agricultural productivity and better resilience of farmers to climatic stresses, but much of this information has been based on staple cereals and not legumes such as common beans. As an example, Weather and Climate Information Services (WCIS), like, seasonal forecasting, advisories, and early

warnings, were found to boost crop yields and enhance resilience in smallholder cereal farmers: in Ethiopia, access to WCIS resulted in higher production of maize and wheat by approximately 27 and 17%, respectively, compared to some traditional inputs such as fertilizers (Tamru *et al.,* 2025). Further, this article has also highlighted that WCIS improves the capacity of farmers to handle climate risk by supplying information in decision-making on when to conduct their operations or when to apply inputs, thus preventing exposure to fatal weather conditions. These results are consistent with the studies that found climate advisories designed specific to farmers made them adjust the planting date, control the moisture level of the soil, and be better equipped to handle rain variability, which led to a higher production stability degree and reduced risks (Tamru *et al.,* 2025; Ngigi and Muange, 2022).

Although this shows the positive influence of a weather-informed decision support system in enhancing crop yields and resilience as a whole, it has been shown that little research exists on the impact of these practices on common bean productivity specifically. Most studies would pool the outcome of crops or may be interested in cereals such as maize or wheat, whose phenology and sensitivities to water stress differ with respect to those of beans. An example is that panel data analysis in Ethiopia determined that, under severe weather, yield losses can be reduced through the adoption of climate-smart practices like improved crop varieties and soil conservation, which consequently improves the resilience, although this study usually takes crops collectively (as opposed to legumes individually) (Asmare and Ojong, 2025). The special physiological sensibilities of beans, particularly to extreme temperatures and drought, suggest that the effects of climate-sensitive practices might vary, but limited research separates the effects of climate to bean systems. This forms a big gap in the comprehension of how WIPs can be applied to generate bean productivity outcomes, in particular and whether resilience advantages experienced in cereals can be applied to legumes with comparable weather risks.

Moreover, the studies indicate that the mediation in the efficacy of WIPs in improving the resilience includes socio-economic and institutional limitations or access to extension services, information channels, and the ability of farmers to interpret and respond to forecasts. The study on smallholder adaptation in East Africa shows that the adoption rate of farmers who have access to climate information is higher

compared to those who don't. This is because they know when to plant, which water management to use, and they use drought-tolerant plants, thus improving yield and resilience (Ngigi and Muange, 2022; Ajwang *et al.,* 2024). Nevertheless, it is also noted in the literature that access to or use of information does not necessarily result in increased productivity or resilience. Unless supplemented by the relevant training, translation of information into feasible practices. This is also supported by the PICSA approach, which indicates that weather and climate information becomes more useful when combined with participatory planning, extension support and locally relevant options (Clarkson *et al.,* 2022; Abidoye *et al.,* 2025). The research addressed these gaps by evaluating bean-specific outcomes of WIPs regarding productivity measures (such as yields) and resilience (such as yield stability, risk avoidance) in the field under Homa Bay Town Sub-County conditions and how climate advisory use interacts with socio-economic aspects to explain the findings.

2.5 Role of Climate-Smart Technologies in Bean Productivity

Common beans have been identified as a major staple crop in Kenya, and play a significant role in food security, nutrition and income generation for smallholder farmers. Although the potential productivity of beans is high, several constraints, such as climate variability, soil fertility, pests and diseases, and limited access to improved inputs and extension services, are still affecting bean productivity (Katungi et al., 2020; Ochieng *et al.,* 2021; Wainaina *et al.,* 2021). In western Kenya, especially Homa Bay County, bean production has been reported as being increasingly affected by erratic rainfall and prolonged dry spells, which increase the risks of production and decrease the stability of yields (Wekesa *et al.,* 2020; Ng'ombe *et al.,* 2020). The difficulties highlight the need for sustainable and adaptive agriculture to boost productivity in the era of climate change.

Empirical studies have shown that the use of climate-smart technologies (CST) is beneficial for bean productivity among smallholder farmers. Improved drought-tolerant varieties, integrated soil fertility management, conservation agriculture and water management techniques are key practices. Improved bean varieties have been linked to higher yields under smallholder conditions, when coupled with good soil fertility management (Katungi *et al.,* 2020; Wainaina *et al.,* 2021). Likewise, soil fertility management practices have been found to increase soil nutrient availability

and crop performance (Mugwe *et al.,* 2021; Manda *et al.,* 2020). Mulching and minimum tillage are practices that have proven to improve soil moisture conservation and yield stability in rain-fed systems (Mutenje *et al.,* 2021; Ng'ombe et al., 2020). In addition, multiple CSTs have been shown to yield higher productivity benefits than single technologies (Manda *et al.,* 2020; Wainaina et al., 2021; Mutenje *et al.,* 2021). The findings show that application of CSTs is one of the main determinants of the productivity of beans, especially in the climate-vulnerable areas such as Homa Bay County.

However, there are some gaps with the existing literature. First, most studies tend to study individual technologies as opposed to the interaction of multiple climate-smart technologies when implemented by farmers. Second, the evidence is largely from experimental or controlled conditions, which do not adequately reflect the realities of on-farm conditions where farmers are subject to a variety of socio-economic and climatic constraints (Manda *et al.,* 2020; Wainaina et al., 2021). Third, little empirical evidence exists linking productivity results of the adopters versus the non-adopters of climate-smart technologies under farmers' conditions. Furthermore, there is limited evidence on the impacts of climate variability and decreasing soil fertility in Homa Bay Town Sub-County. This study aims to address these gaps by assessing the productivity effects of the CSTs under on-farm conditions; comparing productivity outcomes of the bean adopters and non-adopters; and integrating socio-economic factors to offer a more holistic and contextual perspective on productivity outcomes.

2.6 Theoretical Framework

The Diffusion of Innovations Theory and Resilience Theory were used to explain the role of weather and climate information on the uptake of climate-smart technologies and bean productivity of smallholder farmers in Homa Bay County.

Diffusion of Innovations Theory explained the role of weather and climate information services (WCIS) in farmers' adoption of climate-smart technologies (CSTs). Adoption was determined by access to information, perceived advantages, compatibility with existing practices and communication (Rogers, 2003). It provided a basis for Objective 2 through its explanation of how the use of WCIS shaped adoption, which subsequently shaped farming practices.

The idea of resilience of farming systems and their capacity to resist the impacts of climate change and sustain productivity was captured by Resilience Theory (Walker *et al.,* 2004). Limited sensitivity to climate variability and stable bean production were observed as elements of resilience in this project. It was hoped that WCIS and CSTs would increase this capacity, boost decision-making and reduce risk to production.

Theories provided a causal link between WCIS and the adoption of CSTs, through information-based decision-making (Diffusion of Innovations Theory) and by leading to increment of bean production and increment of household resilience (Resilience Theory). This holistic approach facilitated achievement of the study's three objectives by connecting information, adoption and bean production.

2.7 Conceptual Framework

A conceptual framework is a diagrammatic representation of variables in a study. It shows how different variables relate to each other (Figure 2.1).

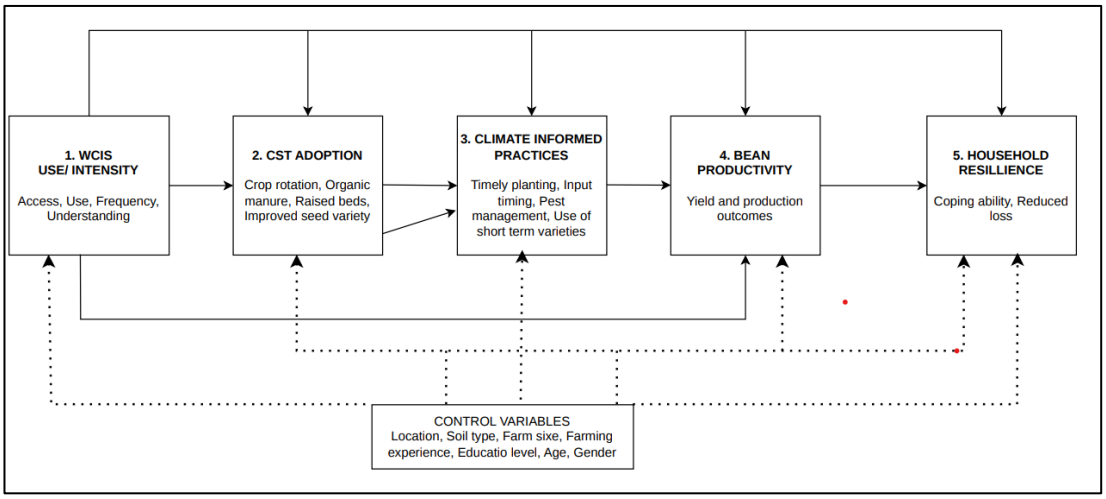


Figure 2.1 Conceptual Framework

Conceptual Framework showing the relationship between independent, moderating, dependent, control and extraneous variables.

2.8 Chapter Summary

This chapter reviewed literature on climate-smart agriculture with a focus on the role of weather and climate information services (WCIS) in smallholder farming under increasing climate variability. Guided by Diffusion of Innovations (DOI) and Resilience Theory, it explained how farmers adopted climate-smart technologies and

how these practices enhanced their capacity to cope with climate-related shocks. The review established that although climate-smart technologies were promoted to improve productivity and resilience, their adoption remained constrained by limited access to information, resources, and institutional support. It further showed that access to timely and reliable climate information improved farm-level decision-making, particularly in relation to planting, input use, and risk management, although its effectiveness depended on accessibility, relevance, and farmers' ability to interpret and apply the information.

The chapter also highlighted the role of weather-informed practices (WIPs) in translating climate information into action, while emphasizing that socio-economic and institutional factors influenced both technology adoption and information use. Despite these insights, the literature largely examined WCIS, climate-smart technologies, and adaptive practices in isolation, with limited evidence on their combined effects, particularly in legume-based systems such as common bean production. This gap was addressed through an integrated approach linking WCIS, climate-smart technologies, and weather-informed practices to productivity and resilience outcomes. The chapter therefore developed a conceptual framework illustrating how climate information influenced the adoption of practices and technologies, and how these interactions, together with underlying factors, shaped farm-level outcomes.

CHAPTER THREE
RESEARCH METHODOLOGY

3.1 Introduction

This chapter describes the methodology used to examine the influence of weather and climate information services (WCIS) on the adoption of climate-smart technologies (CSTs), and the contribution of weather-informed practices (WIPs) to common bean productivity and household resilience among smallholder farmers in Homa Bay Town Sub-County. It presents the study area, research design, target population, sampling procedures, sample size determination, data collection tools and procedures, validity, reliability and piloting of the research instruments, data analysis techniques, and ethical considerations. The chapter further explains how data were collected and analysed in relation to the three study objectives using descriptive statistics, log-linear regression, and integrated structural equation modelling (SEM/path analysis).

3.2 Study Area

This study was carried out within the Homa Bay Town Sub-County in the Homa Bay County within the former Nyanza province. Its borders are to the west to Lake Victoria, east to Rachuonyo South and Suba North Sub-County to the south. It is located between 0 ° 30'S and 0 ° 52'S and 34 ° 25'E and 34 ° 45'E with an area of around 180 square kilometers (Homa Bay County Government, 2023). The sub-county has a bimodal rainfall distribution, that is, the long and short rains between March and June and between September and December, respectively, with an average annual distribution of 800-1,200 mm. The temperature is between 17 °C and 32 °C, which suits the cultivation of food and cash crops, including beans, maize, sorghum, and vegetables.

Homa Bay Town Sub-County has four administrative wards, namely Homa Bay East, Homa Bay Central, Homa Bay *Arujo* and Homa Bay West. All these wards demonstrate different agro-ecological environments, and lakeshore areas (Homa Bay Central and Homa Bay West) are vulnerable to flooding and waterlogging, whereas upland areas (Arujo and Homa Bay East) suffer soil erosion and the stress of droughts (Maarifa Centre, 2023; HCIDP,2023). The sub-county is an exemplary microcosm to study climatic variability effects on agricultural systems due to such diversity.

Smallholder farming is the primary economic activity in the region, with the majority of the households growing beans to serve as a source of household income. Nonetheless, climate variability, inconsistent rainfall distribution, pests, and reduced soil fertility have reduced the productivity of beans (Mabhaudhi *et al.,* 2025). In answer to this, the county government, in partnership with other organizations like the Kenya Meteorological Department and CGIAR initiatives came up with Weather and Climate Information Services (WCIS), to enable farmers to make informed agricultural decisions. Nevertheless, the availability and application of this information are still sporadic and insufficient among the wards, which is a good reason why the given research is relevant.

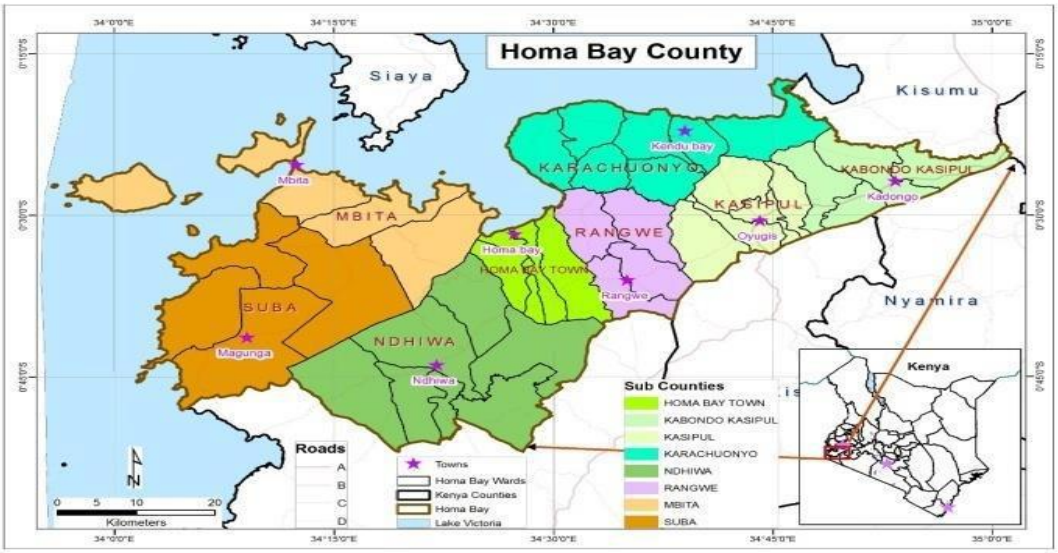


Figure 3.1 Map of Homa Bay County showing the Sub-Counties

3.3 Research Design

The research design of the study was a mixed-methods research design, which consisted of a quasi-experimental study and a household cross-sectional survey to evaluate the impact of Weather and Climate Information Services on the adoption of climate-smart technologies (CSTs), bean productivity and farmers' resilience.

In the quasi-experimental element, randomization was not feasible because, after farmers had received WCIS training, adoption of CSTs occurred naturally based on individual farmers' capacity, resources, and decision-making rather than controlled assignment. A sample of 50 farmers who had undergone WCIS training were purposively selected based on their adoption status. This consisted of 25 farmers who

had adopted CST (treatment group) and 25 farmers who had not adopted CST (control group), but all of them had been exposed to WCIS through training.

Selection bias was minimized by ensuring that both groups had uniform exposure to WCIS training and by applying consistent selection criteria across participants. Additionally, the use of recall data for the same agricultural seasons helped maintain consistency in productivity measurement across participants. Recall information was used to provide data on productivity in the recent growing seasons.

The cross-sectional element involved an addition of 107 more farmers who had been trained on WCIS but were never monitored afterwards. These farmers were chosen to represent the study area more widely. This aspect was meant to produce population-level data on access to WCIS, adoption of CST and the use of climate-informed farming practices and also to determine factors that affect the adoption decisions.

Altogether, the combined design permitted the inference of causality based on the implications of CST adoption using quasi-experimental comparison, whereas the cross-sectional data increased external validity by reflecting broader patterns of access, adoption and farming activities within the study area.

3.4 Target Population

The research focused on the bean farmers of Homa Bay Town Sub-County who had been exposed to the Weather and Climate Information Services (WCIS). The target population was grouped into two categories. The first category was the farmers who had been closely monitored after receiving the training, taking part in the quasi-experimental study, of which some were adopters of CST (treatment group), and others were not (comparison group). The second category included farmers who had undergone training in WCIS but were never monitored; they were involved in the cross-sectional part of the study.

3.5 Sampling Techniques

To select respondents, the study used purposive and simple random sampling. Firstly, the sample size was determined by purposive sampling, which helped to identify the bean farmers in Homa Bay Town Sub-County who have undergone WCIS training,

since the intended population in the study was specifically farmers who are already exposed to WCIS training.

In the quasi-experimental part concerning objective one, 50 farmers who had been significantly monitored after WCIS training were purposively sampled because they had detailed records of production and management. The farmers were then divided into two groups with respect to CST adoption: 25 CST adopters (treatment group) and 25 CST non-adopters (control group). Such a grouping allowed balanced comparison of the bean yield in non-randomized conditions.

In the case of the cross-sectional component, where objectives two and three were addressed, simple random sampling of the training registers was used to select the remaining 107 farmers who had undergone the WCIS training but had not been closely monitored. This guaranteed that every trained farmer had been given equal opportunity to be selected, hence sampling bias was minimized and the sample was more representative.

The mixed method of sampling was suitable for the study because it allowed the rigorous impact assessment in the quasi-experimental conditions, as well as the extended examination of the results of adoption, productivity, and resilience.

3.6 Sampling Size Determination

The sample size of the study was calculated according to the formula offered by Yamane (1967), which is suitable for finite populations and widely used in social research and agriculture.

Below is Yamane's (1967) formula:

$n= N/1+ N(e^2)$

n= Sample size

N= Target population

e = Level of precision set at 0.05 (95% confidence level)

Based on the Sub-County Agricultural report on WCIS training registers, 259 farmers in Homa Bay Town Sub-County were exposed to training. Therefore, the minimum required sample size for the study was 157 farmers.

3.7 Data Collection and Tools

A well-structured questionnaire with both open and closed-ended questions was used to collect primary data by surveying all 157 farmers to get information on household, farm attributes, access and utilization of Weather and Climate Information Services (WCIS), adoption of Climate-Smart Technologies (CSTs), weather-informed management decisions, input use, labour allocation, and bean yields. The 50 farmers participating in the quasi-experimental element (25 CST adopters and 25 non-adopters) had the previous records of productivity and management, and were embedded to confirm the yield estimates through recalls and reinforce the validity in comparison within the field settings. Secondary data, such as supporting data on the rainfall pattern, temperature trends, and CST/WCIS dissemination efforts, were obtained from sources such as the Kenya Meteorological Department, the County Agriculture Office, and project reports.

3.8 Observation Checklist

Recall-based information, given by the quasi-experimental farmers, was validated using an observation checklist, which was used to supplement the data collected through questionnaires among all the respondents. As productivity and management data of the quasi-experimental component were partly based on the recollection of the farmers, the checklist enabled the researcher to conduct systematic checks on observable on-farm indicators that included land preparation, soil conservation structures, crop establishment, evidence of input use, and the overall field conditions. The checklist boosted the accuracy of the self-reported information by offering a standardized set of observable criteria that was used to achieve consistency in documenting the field observations.

3.9 Validity

In order to establish validity, research data were collected using the tools that were directly related to the research goals and variables. Experts in climate-smart agriculture and supervisors revised the questionnaire and observation checklist to ensure that it was content-relevant and understandable. The instruments were pre-

tested on a small sample size of bean farmers within a neighboring ward to determine wording, flow and capturing the intended information. The pre-test feedback was utilized to adjust the tools to ensure that they were able to measure what the study intended.

3.10 Reliability

The consistency of the data collection procedures and the administration of all instruments to the respondents were the reliability measures. The questionnaire had well-designed and focused questions, which minimized ambiguity, whereas the observation checklist had a consistent set of checklists for all farms. The pilot test was used to calculate internal consistency based on Cronbach's alpha, and items with lower reliability were modified. The enumerators were trained on how to achieve consistency in data collection, where the results were constant and reliable with repeated measures.

3.11 Pretesting/ Piloting

The data collection tools were pre tested with a pilot sample of 10 bean farmers in Rachuonyo North Sub-county, Kobuya Ward, which has agroecological and socio-economic characteristics similar to Homa Bay Town Sub-county. The purpose of the pre-test was to determine the level of relevance, order and clarity of the questions, identify any ambiguous or omitted questions from the questionnaire and observation checklist. The pre-test was also used to make tools more friendly and more context-appropriate, by modifying the words, flow and length of the tools to better suit the context. Pre-testing also helped the research team to estimate the amount of time required to complete each tool and helped the enumerators prepare to administer the tools in an optimal way during the actual fieldwork.

The reliability of the questionnaire was assessed using Cronbach’s alpha, which yielded a coefficient of 0.74, exceeding the acceptable threshold of 0.70, thus confirming acceptable internal consistency of the measurement scales.

3.12 Data Collection Procedure

The gathering of data was also performed in stages to ensure accuracy, consistency and ethical guidelines of the research and study. First, the research team was given the necessary approval of the local authorities and introduced the research to the

community leaders and farmer associations. Informed consent was used to collect the data of all the subjects. The whole sample of 157 farmers were then given a face-to-face interview where the organized questionnaire was administered to them so that the questionnaire was filled with the correct answer, and any confusion was clarified. The observation checklist was compared with the recall-based data of the productivity and management practices of the 50 farmers included in the quasi-experimental component to collect and cross-verify. Secondary data were also consulted in areas where the need to do so existed in order to triangulate information. The data collection methodology was carried out in standardized modes to ensure that there was uniformity in the mode of posing the questions, capturing the responses and making the observations. When the tools were completed and checked daily, the tools compilation was made in the analysis.

3.13 Data Analysis

STATA version 19 and Excel were used to analyze the collected data (Table 3.1). The results were also presented using graphs, charts and tables.

Table 3.1 Below shows the summary of research objectives, data type and methods of data analysis

OBJECTIVE	TYPE OF DATA	METHOD OF ANALYSIS
1. To evaluate the effects of climate-smart technologies (CST) on the productivity of common bean under on-farm conditions	Quantitative & qualitative data- bean yield data, adoption status of CST, characteristics of the farm	Descriptive statistics (percentages, frequencies, mean and standard deviation) Log-linear regression Analysis because yield data were positive skewed.
2. To determine how farmers' access to and utilization of weather and climate information services influence the adoption of climate-smart technologies in common bean production.	Quantitative and qualitative data on the status of adoption, WCIS access and use and socio-economic variables will be collected	Descriptive statistics (frequencies, percentages, mean and standard deviation). An Integrated Structural Equation Model (SEM/path analysis) was used to test the relationship between WCIS and CST adoption.
3. Assess the contribution of weather-and climate-informed farming practices on the productivity of common bean and the resilience of households to climate-related risks	Qualitative and quantitative data on yield of beans, weather and climate-informed farming practices, experience of climate-related risks and resilience index/score,	Descriptive statistics (frequencies, percentages, mean and standard deviation). An Integrated Structural Equation Model (SEM/path analysis) was used to evaluate the relationship between WCIS, weather-informed practices, productivity and resilience.

3.14 Ethical Considerations

All ethics and scientific requirements for conducting the research were met and approval was obtained from Murang'a University of Technology Institutional Scientific and Ethics Review Committee (MUT-ISERC) while the research was licensed by the National Commission for Science, Technology and Innovation (NACOSTI) under license number NACOSTI/P/26/4186241.

Information about the aims of the study and the methods of data collection were explained to all participants, who then gave their informed consent. No penalties were given if a respondent refused to take part or withdrew from the study at any time. No personally identifiable information was recorded in the end product and anonymity and confidentiality were maintained throughout the analysis and recording of responses.

Data was stored in password-protected computers accessible only to the researcher and supervisors. The data will be stored for academic review for five years and then destroyed.

3.15 Chapter Summary

This chapter presented the study area and described the research design adopted to examine the role of weather and climate information services (WCIS) in influencing farm-level decision-making, adoption of climate-smart technologies, and productivity and resilience outcomes among smallholder common bean farmers. It outlined the target population, sample size determination, and the multi-stage sampling procedure used to select respondents, ensuring representativeness across the study area.

The chapter further detailed the data collection procedures, including the research instruments used to capture information on WCIS access and use, climate-smart technologies, weather-informed practices, and socio-economic characteristics. It also described the measurement of key study variables and the procedures followed to ensure data reliability and validity, including pilot testing. In addition, the chapter explained the methods of data processing and analysis, combining descriptive statistics with econometric techniques to examine the relationships among WCIS, adoption of practices, productivity, and resilience outcomes. Finally, the ethical considerations observed during the study were highlight

CHAPTER FOUR
RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents and discusses the findings of the study on the influence of weather and climate information services (WCIS) on climate-smart technology (CST) adoption, common bean productivity, and household resilience among smallholder farmers in Homa Bay Town Sub-County. It begins by describing the socio-demographic and farm characteristics of the respondents and then examines the effects of CST adoption intensity on common bean productivity under on-farm conditions. The chapter further presents farmers' access to, sources, utilization and perceived influence of WCIS on farming decisions and CST adoption, including the challenges that affected its effective use. It also examines the adoption of weather-informed farming practices (WIPs), their contribution to bean productivity and loss reduction, and their relationship with household resilience. Finally, an integrated structural equation/path model is presented to establish the interrelationships among WCIS use, CST adoption, WIP intensity, productivity and household resilience, providing an integrated understanding of the pathways through which climate information supported climate adaptation and agricultural outcomes.

4.2 Socio-demographic Characteristics

The common bean farmers in Homa Bay Town Sub-County were observed to be mostly females, with 60.51% female farmers (Table 4.1). This aligns with the prominence of women in legume production and food security for smallholder farming systems that was recently observed (Mabhaudhi *et al,* 2022; Doss *et al.,* 2021; Palacios-Lopez *et al.,* 2022; FAO, 2023). The women's participation in bean cultivation doesn't always imply that they own the land and are decision makers in the farm and home environment. In southern Tanzania, male farmers were more likely than their female counterparts to access support services, own land, and be involved in decision-making regarding climate adaptation in farming (Nchanji *et al.,* 2025). The needs of women farmers in terms of information, resources, and decision-making should, therefore, be considered when designing CSTs and WCIS programmes.

In the age distribution, the majority of 58.60% were aged above 45 years, which was a result of the farmers being relatively old (Table 4.1). The effect of age on the adoption

of new technologies can vary with the technology, labour requirement, farming experience and resource availability. While the younger farmers might be more familiar with the use of digital information services, the relation between age and adoption of CSTs has been mixed in recent studies. Nchanji *et al.* (2025) confirmed that the adoption of improved bean varieties was higher among older male farmers due to their farm experience and resource availability. Further, older farmers were more likely to adopt some of the pest-, disease- and stress-tolerant varieties and climate information, while being less likely to adopt labour-intensive technologies, as found by Mahama *et al.* (2025). It has been found that with age, farmers are not necessarily averse to adopting climate-smart practices. The solutions to share WCIS should thus be designed in a way that is relevant to the different ages, experiences and digital literacy among farmers.

The majority of the respondents (54.14%) had completed primary education (Table 4.1). This demonstrates the need to make climate information easy to understand and accessible. Education is not the only factor that relates to the adoption of climate-smart technologies, but higher levels of education can help farmers access, understand and apply WCIS. Previous research has found that farmers who have more years of education tend to be more willing to follow climate advice and to better comprehend seasonal forecasts, as well as more inclined to use climate-smart technologies (Ariom *et al.,* 2022; Carr *et al.,* 2021; Clarkson *et al.,* 2022; Hansen *et al.,* 2021). WCIS should thus be tailored, accessible and user-friendly by farmers of varying educational levels.

Table 4.1 Socio-demographic characteristics of the respondents

Variable	Category	Percentage %
Gender	Female	60.51
	Male	39.49
	Total	100
Age Distribution	18-35 years	14.65
	36-45 years	26.75
	46-55 years	25.48
	Over 55 years	33.12
Education Level	None	5.73
	Primary	54.14
	Secondary	26.11
	College/University	14.01
Household Size	1-5 members	50.96
	5-10 members	43.31
	Over 10 members	5.73
Primary Source of Income	Farming	95.54
	Business	1.91
	Employment	1.91
	Other	0.64
Farming Experience	Less than 5 years	12.10
	6-10 years	25.48
	11-15 years	10.19
	Over 15 years	52.43

The results also revealed that about 94.27% of the houses had between 1 and 10 members, which shows that most of the households are of smallholder farming groups in Kenya (Table 4.1). Some studies estimate the average household size of between four and eight members in rural farming communities and this may impact the availability of labour and farming decisions (Amare et *al.,* 2021; Wossen *et al.,* 2021; World Bank, 2023; Nchanji *et al.,* 2025). The larger families can supply labour to intercropping and soil and water conservation. But just because there is a large household doesn't necessarily imply adequate farm labour. This can increase farm production and household food security pressures in larger households due to their increased demand for food. Therefore, the labour availability of the household and the consumption needs of the household should be taken into account in CST and WCIS interventions.

The findings also revealed that 95.54% of the respondents were primarily relying on farming for their livelihood (Table 4.1). This implies that agriculture was the main source of livelihood for most households. This dependence can lead to higher exposure to climate variability, particularly given that most farming in the study area is rain-fed. Past research has correlated climate-smart agriculture with better productivity and more stable and adaptive livelihoods for smallholder farmers (World Bank, 2023; Sultan *et al.,* 2021; Birthal *et al.* 2021). The results thus validate the importance of enhancing the access of farmers to information about useful WCIS and appropriate CSTs to support climate risk management.

As far as farming experience is concerned, 52.43% of the respondents had been farming for more than 15 years (Table 4.1). This indicates that there was a lot of practical experience among the farmers. The study did not, however, directly measure indigenous knowledge. Experience on the farm can enhance farmers' ability to make decisions on farming activities, particularly if coupled with timely, clear and locally accessible climate information (Ariom *et al.,* 2022; Mabhaudhi *et al.,* 2022; Hansen *et al.,* 2021; Ogisi, 2024). Therefore, the experience and expertise of farmers should be integrated with WCIS in order to enhance farm decisions, productivity, and resilience.

4.3 Farm Characteristics

The survey results showed that bean production in Homa Bay Town Sub-County was dominated by smallholder farmers, with more than 91% of the respondents cultivating less than 2 acres (Table 4.2). This confirms the smallholder status of farmers in the study area. Limited farm sizes may restrict mechanization and economies of scale. However, they can encourage farmers to adopt low -cost and flexible climate-smart technologies that can be easily applied on small plots. Other recent studies in Kenya and Sub-Saharan Africa highlight that smallholder farmers are more likely to adopt low-cost, flexible Climate-Smart technologies that can be applied to small-scale farming (Ndung'u *et al.,* 2023; Jayne et *al.,* 2021; Liverpool-Tasie *et al.,* 2022). This implies that CSTs interventions in the study region should prioritize affordable, scalable and easy-to-apply technologies suitable for smallholder farmers. The soil types revealed that 50.96% of farmers had black cotton soils and 49.04% had sandy loam soils, suggesting differences in soil conditions within the study area (Table 4.2). These soil differences may have an impact on water holding capacity, drainage, and

nutrient status, which are important for crop yield and adoption of CSTs. Black cotton soils have high moisture retention capacity but are susceptible to waterlogging, whereas sandy loam soils have good drainage but are also prone to moisture stress.

Table 4.2 Farm Characteristics

Variable	Category	Percentage %
Farm in acres	Less than 1 acre	49.04
	1-2 acres	42.04
	2.1-5 acres	5.73
	Over 5 acres	3.18
Type of Soil	Black Cotton Soil	50.96
	Sandy Loam Soil	49.04

Recent studies indicate that soil variability is a crucial element in the performance of climate-smart technologies and yields in the context of climate variability (Hengl *et al.,* 2021; Nyawira *et al.,* 2021; Zingore *et al.,* 2022). CSTs and WCIS interventions should thus be designed to the local context and not as a single intervention for all farmers. With the incorporation of soil-specific measures like application of organic manure, soil moisture conservation and suitable planting decisions, WCIS could help farmers to deal with climate threats under rain-fed bean production systems. This helps farmers adapt to climate variability and yields high production of beans in rain-fed production (Chimonyo *et al.,* 2022; Hansen *et al.,* 2021; Ariom *et al.,* 2022; Tamru *et al.,* 2025).

4.4 Effects of Climate-Smart Technologies on Common Bean Productivity Under On-Farm Conditions

Climate-smart technologies—such as improved seed varieties, soil fertility management, and water-saving practices—can raise common bean yields under farmers' real on-farm conditions. They also help reduce climate-related losses and improve stability of production despite seasonal weather variability.

4.4.1 Descriptive Analysis of CSTs Intensity and Yield Distribution

Productivity generally increased with the CST adoption intensity (Table 4.3; Figure 4.1). The farmers who did not use CST had the lowest mean yield of 135.8 kg/acre, while those using moderate CST bundle had a mean yield of 183.1 kg/acre. Farmers

with high CST bundles had the highest mean yield of 348.2 kg/acre (Table 4.3). The same positive upward trend was observed for the median yields as well, ranging from 118.8 kg/acre for non-adopters to 165.0 kg/acre for moderate adopters and 227.0 kg/acre for high adopters (Table 4.3). The results indicated that common bean productivity increased with increased intensity of CST uptake.

Yield variation was, however, higher among farmers belonging to the high CST category, with a standard deviation of 372.1 kg/acre, compared to 105.1 kg/acre and 67.4 kg/acre among the moderate CST category and non-adopters, respectively (Table 4.3). The corresponding coefficients of variation increased from approximately 50% among non-adopters to 57% among moderate adopters and 107% among high CST adopters, indicating that although intensive CST adoption was associated with higher average productivity, it did not necessarily reduce variability in bean yields**.** As there were only six farmers in the high CST category, the mean yield for this category might have been affected by a few high-yield observations.

Overall, the descriptive results showed a positive association between common bean productivity and intensity of CST adoption. However, descriptive statistics alone cannot determine whether the observed differences among adoption categories are statistically significant. Therefore, inferential statistical analyses were performed to compare productivity across the three CST adoption categories before fitting the multivariable log-linear regression model.

Table 4.3 Yield Distribution by CST Intensity

CST bundle category	N	Mean yield	SD	Median	IQR
No CST	25	135.8	67.4	118.8	95.8-175.0
Moderate CST bundle, 1-4 CSTs	19	183.1	105.1	165.0	121.1-201.1
High CST bundle, ≥ =5 CSTs	6	348.2	372.1	227.0	205.0-238.5
All monitored farmers	50	179.3	157.7	133.8	110.0-200.0

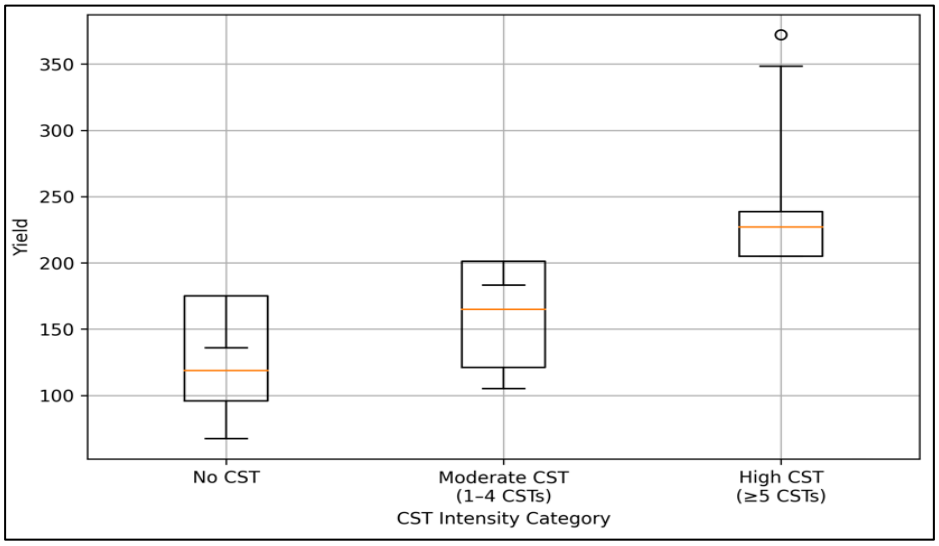


Figure 4.1 Yield Distribution by CST Intensity

To include the variation in technology use among the farmers, climate-smart technology (CST) adoption was converted from a binary variable to CST adoption intensity (bundle categories). The farmers were grouped as no CST, moderate CST bundle (1-4 technologies) and high CST bundle (≥5 technologies) (Figure 4.1). The box plot illustrates an increasing trend in bean productivity with higher CST adoption intensity while also showing greater yield dispersion among farmers adopting high CST bundles.

Table 4.4 Comparison of Common Bean Productivity Across CST Adoption Categories

Statistical test	Test statistic	p-value	Interpretation
Classical one-way ANOVA	F (2, 47) = 5.14	0.010	Significant differences in arithmetic mean yield before assumption checking
Shapiro-Wilk normality test	W= 0.69	<0.001	Residuals deviated significantly from normality
Levene's test	-	<0.001	Homogeneity of variance assumption violated
Welch's ANOVA	F (2, 11.5) = 2.21	0.154	No significant difference after accounting for unequal variances
Games–Howell post hoc test	-	>0.05	No statistically significant pairwise differences
Log-transformed ANOVA	F (2, 47) = 5.54	0.007	Significant differences after satisfying model assumptions
Kruskal–Walli's test	-	0.020	Median yields differed significantly
Jonckheere–Terpstra test	-	0.004	Significant increasing trend in productivity with increasing CST intensity

One-way analysis of variance (ANOVA) was first performed to compare mean yield of common bean among the three categories of the CST. According to classical ANOVA, the groups' arithmetic mean yields were found to be statistically different ($F(2, 47) = 5.14$, $p = 0.010$). However, on the classical ANOVA, the assumptions were found to be violated with diagnostic tests. The residuals were non-normally distributed (Shapiro – Wilk $W = 0.69$, $p < 0.001$) and Levene's test revealed that the variance in yields was not equal across the three adoption groups ($p < 0.001$), suggesting that yield variability among farmers who adopted high-intensity CST bundles was significant.

Therefore, heteroscedasticity-robust ANOVA was conducted (Welch's). Welch's test revealed that differences in arithmetic mean yield were not statistically significant ($F(2, 11.5) = 2.21$, $p = 0.154$), and the Games–Howell post hoc comparisons showed no statistically significant pairwise differences between the adoption categories. The bean yield data were positively skewed and were then log-transformed. After transformation, the assumptions of normality and homogeneity of variance were met,

and ANOVA indicated that significant differences existed between the CST adoption categories ($F(2, 47) = 5.54$, $p = 0.007$). CST farmers who participated in the high-intensity bundles had about 2.08 times the geometric mean yield compared to non-adopters. Additionally, the Kruskal–Wallis's test showed that significant differences existed between the three adoption categories ($p = 0.020$) and the Jonckheere–Terpstra test confirmed that there was a significant increasing trend from low to high as CST adoption intensity increased ($p = 0.004$). These findings collectively indicate that common bean productivity generally increased with increasing intensity of CST adoption despite considerable variability among individual farmers.

4.4.2 Inferential Analysis of CST Intensity and Bean Productivity

Following the comparison of mean productivity across the three CST adoption categories, the relationship between CST adoption and common bean productivity was further examined using a log-linear regression model. The model was based on the natural logarithm of yield because the yield data exhibited a positively skewed distribution. The results showed that CST adoption had a positive and statistically significant effect on common bean productivity (Table 4.5). In the binary model of CST adoption, adopters recorded approximately 37.3% higher bean yield than non-adopters after adjusting for weather and climate information services (WCIS), ward and soil type ($\beta = 0.317$, $p = 0.034$) (Table 4.5). This percentage was obtained using the transformation $\exp(\beta) - 1$ to express the regression coefficient as a percentage change in yield.

The relationship was strengthened and became statistically significant when CST was modelled as adoption intensity. After adjustment, each additional level of CST bundle category had approximately 41.8% more yield ($\beta = 0.349$, $p \leq 0.003$) (Table 4.4). This indicates that the higher the level of adoption of CST, the greater the yield of beans. A better understanding of the results was gained by presenting the results of the CST intensity model, as this revealed that productivity improved with the increased level of adoption of the CST, not just the comparison between adopters and non-adopters.

Table 4.5 Log- Linear Regression Results

Productivity model	Key coefficient	p-value	Interpretation
Log-yield model with binary CST adoption	beta = 0.317	0.034	CST adopters had approximately 37.3% higher yield than non-adopters after adjustment.
Log-yield model with CST bundle category	beta = 0.349	0.003	Each higher CST bundle category was associated with approximately 41.8% higher yield after adjustment.

The findings indicated that increasing the intensity of climate-smart technologies adoption was positively associated with the productivity of smallholder common bean farmers. The significant differences observed in the log-transformed ANOVA and the subsequent log-linear regression consistently demonstrated that higher levels of CST adoption were associated with increased common bean productivity. The results do not imply, however, that any given bundle performed better than any given technology combination, because the model was not evaluating the impact of each technology combination, but rather the intensity of adoption. This suggests that productivity gains were associated with increasing levels of CST uptake rather than any specific combination of technologies**.** The results were consistent with the findings of Mutenje *et al.* (2021), who found that the adoption of climate-smart agricultural technologies enhances productivity more when combined in bundles than when implemented alone. Likewise, Manda *et al.* (2020) reported that the synergies of grouping climate-smart practices have a significant impact on the productivity of agriculture. The findings of Wainaina et al. (2021) also demonstrated that the adoption of integrated management of soil and water in rain-fed systems enhances productivity. Similarly, in Kenya, Okello *et al.* (2022) found that the higher yield potential of improved bean varieties, coupled with soil fertility management, increases yield for smallholder farmers.

The findings also indicated greater yield variations amongst the farmers, particularly in the high CST category. The increasing coefficient of variation from approximately 50% among non-adopters to 107% among high CST adopters, together with the unequal variances observed across the adoption categories, indicates that although higher CST adoption was associated with greater average productivity, the magnitude

of productivity gains varied considerably among farmers. These findings echo those of Chimonyo *et al.* (2022), who reported that the effectiveness of climate-smart technologies is dependent on agro-ecological conditions, access to resources and farm management. However, the differences found in this study might be attributed to differences in the way the technologies were adopted by farmers, not necessarily to the fact that the general relationship between adoption of CSTs and productivity was weak. Other research has also found mixed or variable productivity impacts of climate-smart and agronomic interventions. For instance, according to Aker *et al.* (2022), the effects of agricultural interventions can vary depending on the level of access to inputs, farmers' ability and environmental conditions. These contextual differences may explain why the overall relationship between CST adoption intensity and productivity remained positive, while the magnitude of yield improvement differed across individual farmers.

Overall, the findings demonstrate that increasing the intensity of climate-smart technology adoption significantly improved common bean productivity under on-farm conditions. However, the observed variability in yield responses suggests that maximizing the productivity benefits of climate-smart technologies requires consideration of local agro-ecological conditions, farmers' resource endowment and management practices**.**

4.5 Influence of Weather and Climate Information Services on the Adoption of Climate-Smart Technologies

Weather and climate information services provide timely, location-specific forecasts and risk guidance that help farmers and agribusiness plan and manage climate variability.

4.5.1 Access, Sources and Frequency of Weather and Climate Information Services

In Table 4.6 and illustrated in Figure 4 .2, the common bean farmers in Homa Bay Town Sub-County had been exposed to weather and climate information services (WCIS), as all the respondents reported having access to weather and climate information. This was anticipated as the study was conducted with a group of farmers who were previously trained in WCIS. The main communication channels were radio (94.90%) and SMS dissemination (85.99%) followed by the TV (45.86%) (Table 4.6;

Figure 4.2). Extension officers (8.28%) and NGOs/projects (8.92%) were the least reported sources of WCIS. By frequency, 52.87 % of farmers received WCIS once a week, and 38.85 % of them received it daily (Table 4.6).

Results showed that there was general access to climate information in the study area, which was strongly mass-dependent. Radio and SMS were the primary means of communication used by the farmers as they were easy to access, cost-effective and time-efficient. The results are in line with the results of other studies in sub-Saharan Africa that showed that radio and cell phones are still the most effective platforms for disseminating information to smallholder farmers owing to their affordability and availability to rural farmers (Fikadu *et al.,* 2024; Tesfaye *et al.,* 2023; Ochieng *et al.,* 2022).

Farmers' exposure to climate information was high due to the frequent delivery of WCIS. Farmers' access to WCIS and its high frequency does not mean that they use the information in all their farming decisions. Potential benefits for farmers' response to climate change variability and seasonal climate prediction uncertainty from short-range and medium-range climate prediction have also been shown (Hansen *et al.* 2021). Yet, Belay *et al.* (2022) revealed that having access to information is not enough to ensure adaptation action in the face of structural constraints like low capital and limited extension services. The findings, therefore, supported that access to the WCIS was good among sampled farmers, but usage of the information depended on the type of farming decisions.

Table 4.6 Access, Sources and Frequency of WCIS

Variable	Category	Percentage %
Access to WCIS	Yes	100
Sources of WCIS	Radio	94.90
	SMS	85.99
	TV	45.86
	Social media	21.02
	Farmer Groups	18.47
	Others (Friends, neighbors, lead farmers)	18.47
	Mobile Apps	9.55
	NGOs/Projects	8.92
	Extension Officers	8.28
Frequency of receiving WCIS	Weekly	52.87
	Daily	38.85
	Monthly	5.73
	Only before planting	2.55

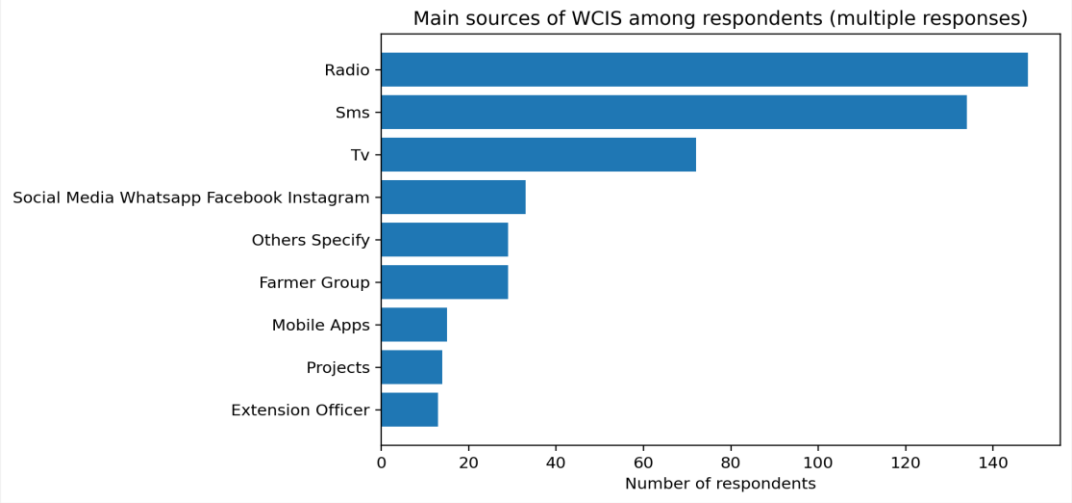


Figure 4.2 Main sources of WCIS reported by respondents

4.5.2 Utilization and Influence of WCIS on Farming Decisions

According to the results presented in Table 4.7, WCIS was mostly used in time-sensitive agricultural decisions. The majority of farmers relied on climate information

in planning their planting dates (98.09%) and in preparing land (92.99%), while lesser numbers of farmers used it to manage pests and diseases (15.92%), apply fertilizer (18.47%) and schedule their irrigation (1.91%) (Table 4.7). Moreover, 59.24% of respondents indicated that WCIS did affect their adoption of CSTs, the majority of which (35.03%) reported moderate effects (Table 4.7).

Results showed that farmers mainly used weather and climate information for low-cost activities and time-related activities on the farm, but not for resource-intensive management procedures. WCIS dependence for planting and land preparation demonstrated the significance of the rain-fed agricultural systems and the importance of forecasts of rainfall. The same result was obtained by Chimonyo *et al.* (2022), Partey *et al.* (2022), and Clarkson *et al.* (2022), who noted that the planting program and land preparation are affected by seasonal and short-term forecasts among smallholder farmers. The moderate influence of WCIS on CST adoption further suggested that climate information was not a sufficient factor on its own to drive CST adoption, but rather an enabling factor. The identified finding is consistent with the other studies carried out by Sisay *et al.* (2023), Belay *et al.* (2022) and Aker *et al.* (2022), which suggest that financial, institutional and socio-economic factors, in addition to information availability, affect the adoption of climate-smart technologies.

Table 4.7 Utilization and Influence of WCIS on Farming Decisions and CSTs Adoption

Variable	Category	Percentage %
Decisions made	Setting plant date	98.09
	Land preparation	92.99
	Harvest timing	28.66
	Fertilizer application	18.47
	Pest/disease management	15.92
	Irrigation scheduling	1.91
Influence of WCIS on CSTs Adoption	Yes	59.24
	No	40.76
Extent of Influence	Moderate	35.03
	Low	12.10
	High	8.92
	Very High	3.18

The low level of WCIS use in irrigation planning and input management partially differs from the use of climate information in other irrigation or commercial farming systems, such as those using climate information for irrigation planning and fertilizer scheduling (Zondo *et al.,* 2024). The difference could be due to the mainly rain-fed and resource-limited production systems in the study area. As a result, farmers had fewer opportunities to apply WCIS in irrigation scheduling even when they had access to weather and climate information. Overall, the findings indicated that WCIS positively influenced climate adaptation decision-making among common bean farmers, especially time-sensitive decisions such as adjusting planting dates and land preparations. However, it had a weak influence on capital-intensive decisions such as fertilizer application, pest management and irrigation scheduling.

4.5.3 Climate-Smart Technologies Influenced by WCIS

The WCIS mainly influenced the adoption of intercropping (54.14%) and the use of organic manure (50.32%), as shown in Figure 4.3. The moderate influence was seen in the improved adoption of seeds (31.85%) and improved crop rotation (28.03%), while mulching was at a very low level of adoption (1.91%) and zai pits (1.27%) (Figure 4.3). Moreover, 40.76% of the respondents said that WCIS had not influenced their adoption of any climate-smart technology (Figure 4.3). This shows that access to WCIS did not automatically lead to technology adoption among all farmers.

The results showed that the promotion of climate information mainly led to the adoption of flexible, low-cost, and risk-reducing adaptation measures that are relevant to the smallholder farming systems. Intercropping and the use of organic manure practices have been identified as low-cost methods to enhance water holding capacity and mitigate climate change impacts to production. This is supported by the results of Sisay *et al.* (2023) and Partey *et al.* (2022), which indicated that the climate-smart practices with lower risk of implementation and financial costs are more likely to be adopted by the smallholder farmers.

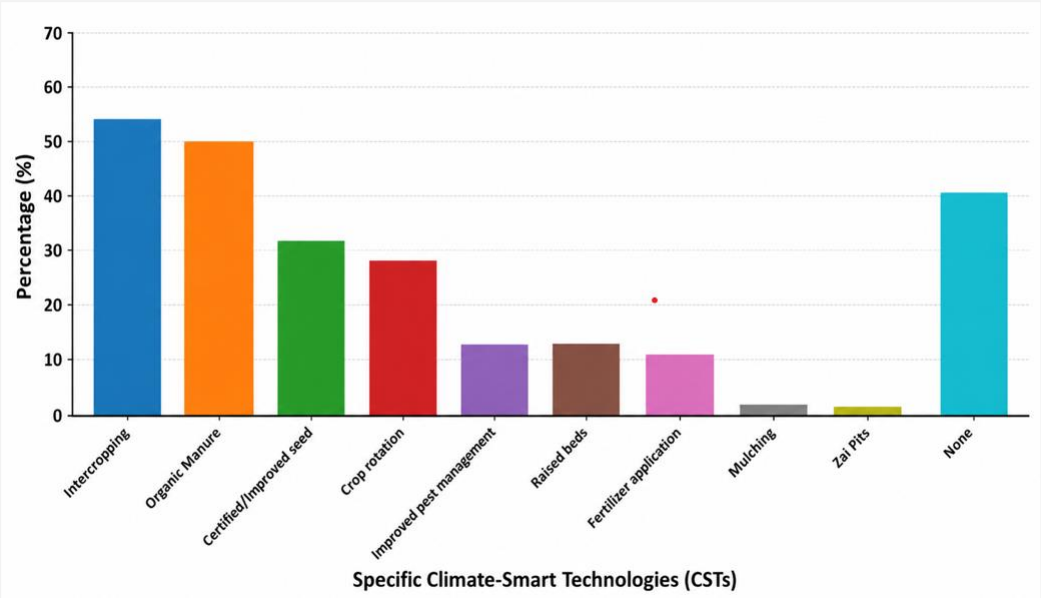


Figure 4.3 Specific CSTs adopted

The low influence of WCIS on resource-intensive practices like mulching and zai pits implied that climate information was not enough to spur the adoption of resource-demanding technologies. Similarly, Belay *et al.* (2022) and Chimonyo *et al.* (2022) found that the availability of labour, extension service, financial resources and farm inputs is important for successful adoption of intensive adaptation technologies. There was also an information-action gap, with 40.76% of respondents saying there was no influence of WCIS on CST adoption. Some farmers might not have had the resources, inputs, labour or technical assistance to translate the weather and climate information into technology in their context. This suggests the need to ensure that WCIS is complemented with concrete assistance such as extension services, farmer input and farmer education, all of which are enablers of technology uptake. From the descriptive

results, it can be concluded that there was a positive correlation between WCIS and the implementation of some CSTs, especially the low-cost and flexible CSTs.

4.5.4 Challenges in Accessing Weather and Climate Information Services

Figure 4.4 revealed that many farmers faced several challenges in using WCIS effectively, even though all of them had access to WCIS. The main challenges were unreliable forecasts (98.73%), irregular updates (94.90%), and distrust of information providers (67.52%) (Figure 4.4). In addition, farmers reported technical complexity and information costs as challenges to effective use.

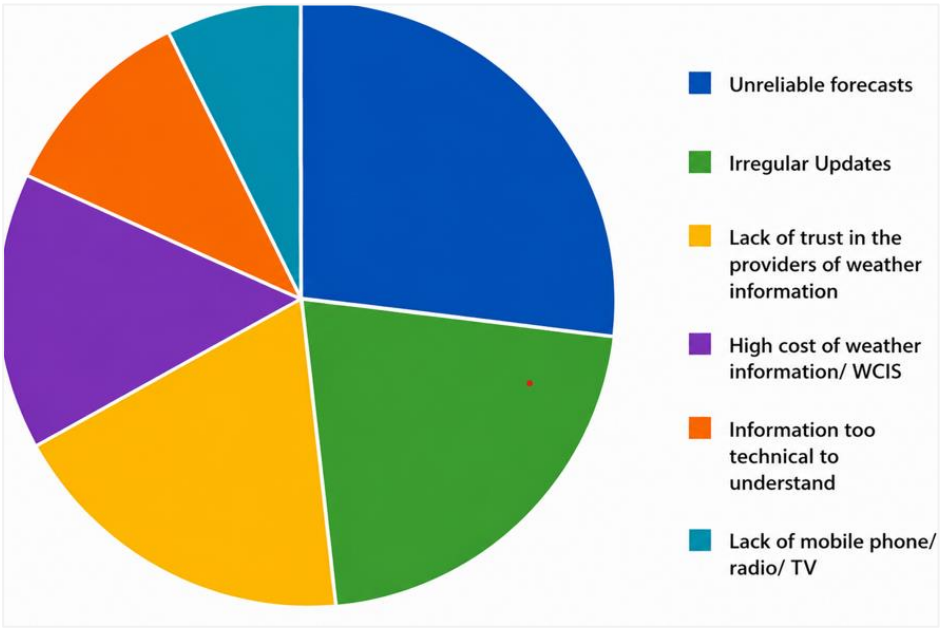


Figure 4.4 Challenges in Accessing WCIS

The findings showed that access to WCIS alone was not a determinant for the effectiveness of weather and climate information services, but also its reliability, trust, timeliness and relevance to the local context. As found by Khatibu and Ngowi (2025), Ochieng *et al.* (2022), and Tesfaye *et al.* (2023), the main obstacles for using weather and climate information services by farmers are distrust, delayed delivery of the information about forecast data, and uncertainty in seasonal forecasting. Likewise, the utility of CSTs depends on whether farmers perceive the WCIS to be relevant, locally applicable, and actionable. Previous studies have also shown that farmers are more likely to trust and use WCIS when it is supported by extension services and localized advisories. For instance, Hansen *et al.* (2021) and Clarkson *et al.* (2022) found that

interpretation support, participatory climate advisories and community-based communication systems improved farmers' trust and uptake of climate information.

This finding is also supported by the Participatory Integrated Climate Services for Agriculture (PICSA) approach. PICSA emphasizes the use of localized climate information, farmers' own knowledge and participatory planning to help farmers make better farm decisions. This approach is relevant to the present study because farmers reported challenges such as unreliable forecasts, irregular updates, distrust of information providers and technical complexity. Therefore, WCIS should not only be shared through radio and SMS, but should also be supported by extension services and participatory interpretation. This can help farmers understand the information better and apply it to their own farming conditions (Clarkson *et al.,* 2022; Abidoye *et al.,* 2025). These challenges help to explain why access to WCIS did not always translate into higher CST adoption, productivity improvement and resilience outcomes among all farmers. Forecast reliability, usefulness and farmers' ability to understand and apply the information may have influenced how well WCIS supported adaptation decisions. Therefore, the findings show that effective climate services require more than dissemination. They also require credible information providers, timely updates, locally relevant forecasts and practical support to help farmers apply the information in their farming decisions.

4.6 Contribution of Weather- and Climate-Informed Farming Practices to Bean Productivity and Farmers' Resilience to Climate-Related Risks

Weather and climate-informed farming practices use forecasts, seasonal climate outlooks, and early warnings to guide timely planting, irrigation, and input management. This strengthens bean productivity while improving farmers' resilience to climate-related risks such as drought, floods, and heat stress.

4.6.1 Adoption and Types of Weather and Climate-Informed Practices

Table 4.8 indicates that all the respondents adopted at least one of the farming practices related to WCIS. The main ones were planting date changes (96.82%) and the use of short-maturity crop varieties (96.18%) (Table 4.8). The other practices included certified seed (31.21%), adjusting the harvest date (29.30%), conserving soil moisture (24.20%), pest and disease management (19.11%) and scheduled fertilizer application (17.83%) (Table 4.8). The findings indicated that farmers of common beans in their

day-to-day farming have incorporated the adoption of WCIS in their decision-making process. The main use of climate information by farmers was to support timing-related adaptation measures to minimize the uncertainties and risks associated with rainfall. The planting-date adjustment and use of short-maturity varieties also identified the farmers' efforts to practice low-cost and easily implemented practices. (Wekesa and Njuki, 2023) and Kurgat *et al.* (2020) similarly reported that smallholder farmers start with less resource-demanding climate adaptation technologies and then progress towards more resource-demanding technologies as the need arises.

Table 4.8 Adoption and Types of Weather- and Climate-informed farming practices

Variable	Category	Percentages %
Adoption of Weather and Climate-Informed Practices	Yes	100
Types of Practices adopted	Adjusted planting date	96.82
	Use of short-term maturity	96.18
	Use of certified seeds	31.21
	Set when to harvest	29.30
	Conservation of soil moisture	24.20
	Pest/disease management	19.11
	Scheduled Fertilizer application	17.83

The findings were also in line with those of (FAO,2023), where it was concluded that the most effective approach to integrate climate information would be to incorporate it in the practical decision-making processes of the farms. However, more complex adaptation strategies like financial constraints, weak extension services, and access to agricultural inputs were reported as limiting factors in their adoption by Mwangi *et al.* (2024).

The present study revealed that for common bean production systems, adaptation strategies that address the timing are also relevant, as many studies addressing climate adaptation focused on cereals.

4.6.2 Contribution of WCIS on Bean Yield or Loss Reduction

The findings of Table 4.9 showed that there was a correlation between farmers' productivity of the Bean and the use of weather and climate information services

(WCIS) in farming. In particular, 60.51% reported slightly higher yields, and 24.20% reported substantially higher yields after using climate-informed practices (Table 4.9). However, 14.65% farmers indicated that their yields remained unchanged, and 0.64 % farmers indicated a slight decrease in their yields (Table 4.9). Moreover, 78.98% of the farmers said that the use of Climate Smart Practices helped reduce the losses of the yields (Table 4.9). The findings showed positive effects of the use of WCIS on productivity and risk reduction of bean production systems. The results indicate that if farmers' choices regarding planting dates, the establishment and field management of crops were adjusted to align with the climate information provided, they were more likely to make gains in production in response to rainfall variability scenarios.

Table 4.9 Perceived Impact of WCIS on Bean Yield or Losses

Variable	Category	Percentage %
Perceived Yield Change distribution	Slightly higher	60.51
	Much higher	24.20
	No change	14.65
	Slightly lower	0.64
Crop loss reduction perception	Yes	78.98
	No	21.02

The results are comparable to those of Tamru *et al.* (2025), which shows that the benefit of climate information is related to better timing of the agricultural activities, to foster agricultural productivity. Likewise, Asmare and Tabe Ojong (2025) found that climate-smart agriculture improves productivity outcomes in terms of their stability in the face of climatic stresses. Co-packaged approaches to adoption appear to be important, with Mwangi *et al.* (2024) finding that the productivity shift for multiple CT interventions was greater than the shift for either of the individual interventions. Some farmers, however, reported no change due to productivity gains, indicating that not all farmers reaped the benefits of increased productivity. The differences in outcomes reported could be attributed to differences in access to resources, access to inputs, labour availability and their ability to implement the recommendations coming out of the climate change. In this context, FAO (2023) pointed out that climate services are best complemented by other enabling tools such as agricultural extension, availability of inputs, and sound institutional arrangements.

4.6.3 Drivers of Yield Improvement

The results shown in Figure 4.5 suggested that there were several interacting factors that enhanced the productivity of beans, with the most significant being weather updates and integrated adaptation strategies. Other factors, such as early maturing varieties, certified seeds and planting date adjustment, made a relatively high contribution to productivity increase, with soil amendments and pest management being relatively low (Figure 4.5). The results indicated that it is the farm-based decision-making process in combination with the climate information and not one specific practice per se that contributed to the productivity improvements. Weather information is crucial for making decisions on when to plant and other critical production decisions during periods of rainfall variability, indicating the critical role played by WCIS in this context.

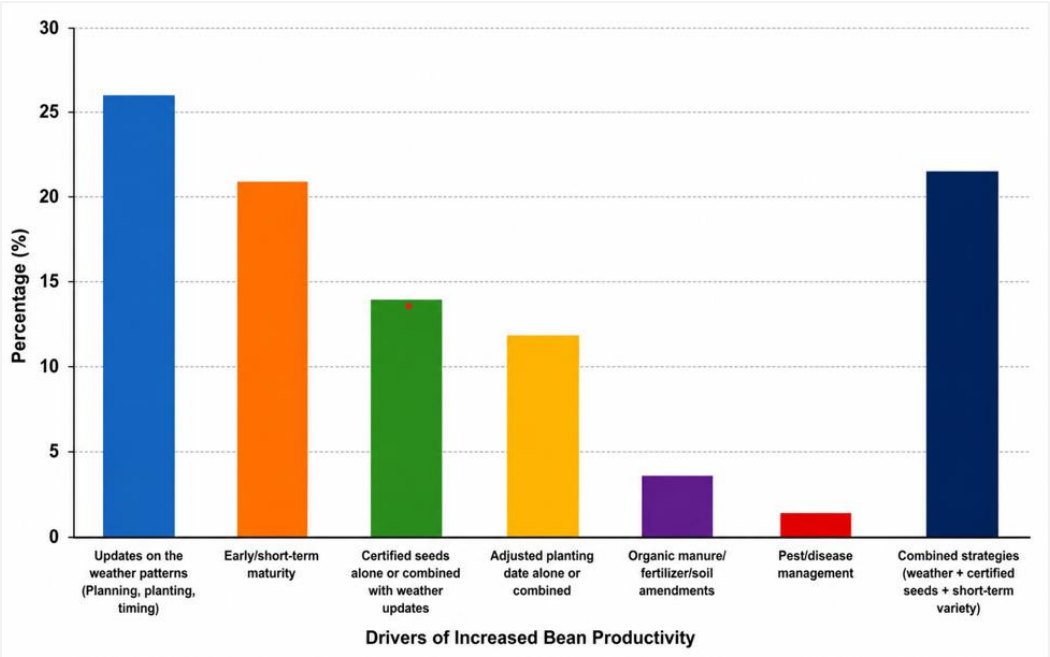


Figure 4.5 Drivers of Increased Bean Productivity

The results align with the results of Mwangi *et al.* (2024) and Tamru *et al.* (2025), who observed that synergies of an integrated package of adaptation measures are more productive than individual adaptation measures. Similarly, FAO (2023) emphasized the need to use climate services in a coordinated manner with extension services and the availability of agricultural inputs that can help with on-the-ground implementation by farmers. The relatively lower input of soil amendments and pest management

indicates structural constraints, which are also mentioned by Kurgat *et al.* (2020), that, in particular, are limiting the access to inputs and financial resources of the smallholder farmers.

4.6.4 Household Resilience

Table 4.10 shows the components of the household resilience index, and Figure 4.6 shows the scores for resilience by categories of adoption of the CSTs. The mean score for the reduced climate-related losses was 3.87, indicating a high level of reduced losses reported by farmers. Likewise, household food security had a high mean score of 3.96, meaning that the production of beans under weather and climate information has a positive impact on household food security (Table 4.10). The overall standardized composite household resilience index obtained was 0.07, indicating medium overall resilience of the sampled households. Moreover, it was found that the resilience varies according to the adoption of different levels of Climate-Smart Technology (CST). Farmers with a higher intensity of CST adoption had higher resilience scores than farmers with low and non-adopting farmers (Figure 4.6).

Table 4.10 Components and Coding of Resilience Index

Indicator	Description	Measurement Scale	Mean Score
Reduced Climate-related losses	Farmer perception that WCIS-supported practices reduced production losses caused by drought or erratic rainfall	Likert scale (1-5)	3.87
Improved household food security	Perception that bean production supported by climate information improves household food availability	Likert scale (1-5)	3.96
Composite Resilience Index	Aggregated standardized score		0.07

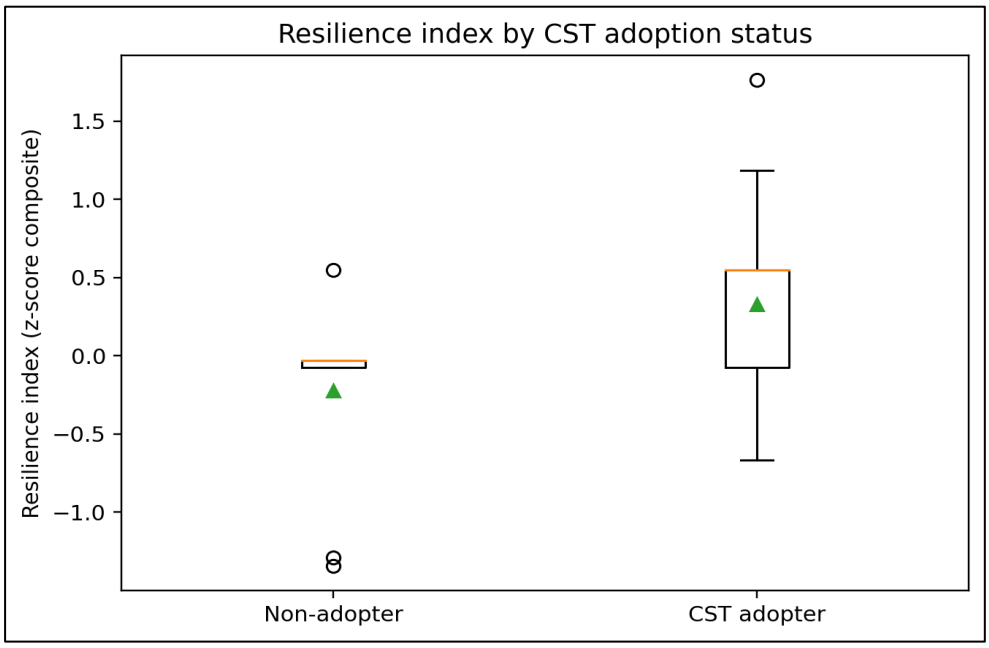


Figure 4.6 Resilience index by CST adoption

The pattern suggested that the climate adaptation pathways integrated (WCIS, CST, and implementing weather-informed farm management practices) were linked with the resilience outcomes among common bean farmers. The findings supported the study's research hypothesis that practicing weather and climate-informed practices is a significant factor contributing to household resilience in the study area. The findings were similar to recent studies, which found that adoption of climate-smart agricultural

practices increased the adaptive capacity, lowered vulnerability, and increased livelihood stability of smallholder farming households (Asmare & Tabe Ojong, 2025; World Bank, 2024). Likewise, Zheng *et al.* (2024) found that focusing on resilience enhancements was correlated with integrated adaptation strategies, rather than individual adaptations.

The results also showed that resilience was not only associated with the level of climate risk exposure, but also with the adaptability of the farmers to climate change by their acceptance and adoption of suitable climate adaptation measures. This is aligned with the resilience level as mentioned by the FAO (2023) and which has adaptive capacity and relevant adaptation tools. Despite all these developments, some farmers reported constraints on the accuracy of the forecasts, lack of extension support and availability of inputs. These limitations are likely to have lowered all families' overall resilience benefits. The results overall showed that the adoption of WCIS and CST was associated with increased household resilience, both directly as a result of the improved decision-making capacity and indirectly as a result of improved productivity and adoption of climate-informed farming practices.

4.7 Integrated SEM/ Path Model linking WCIS, CST Adoption, Weather-Informed Practices, Productivity and Resilience

To accomplish the study objectives, an integrated composite-based Structural Equation Model (SEM)/path model was developed to show the relationship between Weather and Climate Information Services (WCIS) and Climate-Smart Technology (CST) adoption intensity, weather- -informed practice (WIP) intensity, bean productivity, and household resilience. The study variables were conceptually interrelated, and so the integrated model was used. Specifically, it was predicted that use of WCIS would result in increased uptake of CST and increased uptake of weather-informed practice, which would in turn have a relationship with increased bean productivity and household resilience. Observed composite indices from responses to questionnaires and the productivity data monitored were used to estimate the SEM/path model.

The exogenous construct was WCIS use/intensity, and the mediating constructs were CST adoption intensity and WIP intensity. Productivity of beans and resilience of the households were considered as outcome constructs. To check for the consistency

between the components, the reliability of the composite indicators was tested before the model estimation. The standardized path coefficient, the p-values of the study variables, and the indirect relationship between the study variables were used as an interpretation for models. Non-normal and variable yields (when applicable) were treated by the use of standard errors and bootstrapping procedures. Goodness of fit statistics were used to analyze the model for goodness of fit, which was recommended with the cut-off values for the Chi-square to degrees of freedom ratio(χ^2/df), Root Mean Square Error of Approximation (RMSEA), Comparative Fit Index (CFI), Tucker-Lewis Index (TLI) and Standard Root Mean Square Residual (SRMR) statistics, and the model was found to fit the data well.

Table 4.11 Integrated SEM/ Path Model

Path	Standardized beta	p-value	Interpretation
WCIS decisions -> CST intensity	0.447	<0.001	Farmers using WCIS for more decisions adopted/integrated more CSTs.
WCIS perception -> CST intensity	0.356	<0.001	Better understanding and perceived usefulness of WCIS increased CST adoption intensity.
CST intensity -> WIP intensity	0.386	<0.001	CST adoption was strongly linked to broader weather-informed practice use.
WCIS decisions -> WIP intensity	0.300	<0.001	Use of WCIS for farming decisions directly increased weather-informed practices.
WCIS perception -> WIP intensity	0.288	<0.001	Positive WCIS perceptions supported weather-informed practice intensity.
WIP intensity -> productivity	0.361	0.001	Weather-informed practices were positively associated with improved bean productivity.
CST intensity -> productivity	0.215	0.029	CST intensity had an independent positive productivity effect.
WCIS perception -> productivity	0.260	0.001	Useful and understandable WCIS was linked with productivity improvement.
Productivity -> resilience	0.341	<0.001	Higher productivity improvement translated into stronger household resilience.
WCIS perception -> resilience	0.391	<0.001	WCIS also had a direct resilience contribution through planning confidence and risk reduction.

The integrated SEM/path model indicated that WCIS had a significant impact on the intensity of climate-smart technology (CST) adoption by common bean farmers. Positive perceptions about the usefulness and clarity of WCIS, and the frequency with which farmers used WCIS to make farm decisions, significantly increased their intensity of adoption and integration of multiple CSTs ($\beta = 0.447$, $p \leq 0.001$). The

results indicate a need for more than just raising awareness of the farmers, as climate information services are having a significant influence on their adaptive behaviour. The findings suggest that the likelihood of farmers adopting climate-smart innovations is increased when the information is understandable, relevant at the farm level, and directly applicable to farm decisions. This reinforces the notion that climate information helps to build farmers' adaptive decision-making capacity and climate-resilient agricultural transformation.

This finding is consistent with recent research in Sub-Saharan Africa that shows that localized and farmer-adapted climate information has a significant impact on farmers' crop technology and uptake of adaptation measures, such as the introduction of technologies and practices of climate-smart agriculture (CSA) (Khatibu & Ngowi, 2023; Nhamo *et al.,* 2021). Similarly, Zheng *et al.* (2024) found that farmers' climate-informed farming planning efforts were more likely to be successful in implementing climate-smart farming practices. The results also support the assertion of Alhassan and Haruna (2024) that the usefulness, availability, and comprehensibility of the climate information were more important to the farmers. Therefore, the present study emphasizes the need for access to both WCIS and its usability and contextual relevance to the farming systems to be improved.

The results, however, differ from those of Belay *et al.* (2022) and Zondo *et al.* (2024), who suggested that financial, institutional and infrastructural challenges may prevent access to climate information from leading to uptake of climate-smart technologies. While similar barriers are still relevant in many rural farming systems, the current study revealed that the intensity of WCIS use and farmers' perceptions of the usefulness of the WCIS were significantly correlated with the intensity of the adoption of CST. This indicates that climate information services can be effective not just if they are available, but if farmers can interpret, trust and be able to incorporate the information into their normal agricultural decision-making processes.

Further, intensity of the CST adoption was found to have a positive effect on intensity of WIP among the farmers ($\beta = 0.386$, $p \leq 0.001$) in the SEM/path model. Farmers who adopted more than one of the climate-smart technologies reported greater adoption of more climate-informed management practices, such as shifting planting dates, planting early maturing bean varieties, conserving soil moisture, and adjusting

the timing of fertilizer application. Positive perceptions of WCIS ($\beta = 0.288$, $p < .001$) and WCIS-informed decision-making ($\beta = 0.300$, $p < .001$) both had positive and significant effects on the intensity of weather-informed practices. These links highlight that use of climate-smart technology and weather-informed farm management practices are not mutually exclusive and are complementary approaches for adaptation (Hansen *et al.,*2021; Ariom *et al.,*2022; Tamru *et al.,*2025). These results thus suggest that the active use of climate information can be beneficial for farmers to make effective and timely decisions on what to do with the forecast.

The results supported the hypothesis that WCIS is contributing significantly towards improving climate-informed agricultural activities. The findings indicate that good and clear weather information increases farmers' anticipatory capacity, and thus supports their decision-making process in advance of the weather, under conditions of climate uncertainty. This underscores the importance of mainstreaming climate information services within other agricultural adaptation programmes at the farm and farmer level, as well as linking with each other to improve climate variability preparedness and responsiveness (Hansen *et al.,*2021; Nhamo *et al.,*2021)

The integrated SEM/path model also revealed that the practice intensity of using the weather information significantly positively correlated with bean productivity improvement ($\beta = 0.361$, $p = .001$). Similarly, independent of each other, adoption intensity of CST was positively related to productivity improvement ($\beta = 0.215$, $p = .029$), and positive perceptions of WCIS were positively related to productivity outcomes ($\beta = 0.260$, $p = .001$). The results provide further evidence that synergies between climate-smart technologies, climate-informed farm management, and climate-informed use of weather and climate information services had a strong impact on productivity gains among common bean farmers (Ariom *et al.,*2022; Mabhaudhi *et al.,*2022). The outcomes suggest that farmers who used the weather information effectively in their farm operations were more likely to make better production decisions, mitigate losses attributed to climate, and make better overall production decisions.

The findings also confirm the study hypothesis that adaptation practices and weather-informed decision-making play a significant role in agricultural productivity improvement as a result of climate change. The positive correlation of WCIS and

productivity indicates the potential of using timely and actionable climate information to improve the efficiency of farm management and improve the robustness of agricultural systems by enhancing adaptability. The findings thus point to a potential role for climate information services in improving sustainable productivity through the provision of climate-informed and climate-sensitive farming options (Zingore *et al.,*2022; Tamru *et al.,*2025)

Household productivity improvement also had a significant effect on household resilience in the integrated SEM/path model ($\beta = 0.341$, $p < .001$). In addition to the indirect impact through productivity improvements, this study found that WCIS had a significant and positive direct effect on household resilience ($\beta = 0.391$, $p < .001$). This association indicates that better climate information services increased farmers' planning confidence, decreased uncertainty, increased climate risk management capacity and improved farmers' capacity to respond to climatic shocks and variability (Hansen et al.,2021; Ariom *et al.,*2022; Tamru *et al.,*2025). The results suggest that resilience of farming households is not only reflected in their productivity results but also in their capacity to anticipate, prepare and react to climate risks.

The findings support the hypothesis that farmer's climate variability and production risk resilience has an important component in terms of their WCIS and climate adaptation practices. The biggest resilience gains associated with upscaling climate information and adaptation practices were increased productivity, improved food security, decreased production losses and increased adaptive capacity (Ariom *et al.,*2022; Tamru *et al.,*2025). So, the findings indicate that the direct and indirect links that climate information services have with resilience are through improved adaptation actions, improved pathways for livelihood productivity and improved livelihood stability.

The integrated SEM/path approach was an important methodological advance over previous studies on climate adaptation, which were limited in that one approach was either used as a standalone method or employed in isolation. Existing research and analysis on the theme of weather and climate information services, climate-smart technology uptake, productivity and resilience are mostly carried out as single or isolated studies, without establishing linkages between climate information and adaptation and livelihood outcomes to date (Hansen *et al.,*2021; Belay *et al.,* 2022;

Nhamo *et al.,* 2021; Tamru *et al.,* 2025) The current study, however, has integrated all the study objectives into a logical analytical structure related to the use of WCIS and the level of CST adoption, weather-informed practices, productivity changes and household resilience. This holistic view yields a more complete picture of the adaptation processes of smallholder farmers and illustrates how climate information can affect agricultural resilience and does so in various ways.

Overall, the SEM/path model supported the conceptual model of the study by showing that the intensity of adopting CST practices and weather-informed farming practices was significantly higher with the increase of WCIS, which further led to an increase in bean productivity among the farmers and household resilience. The results thus confirm that weather and climate information services are key for the direct and indirect promotion of adaptive agricultural behaviour and resilience in an interconnected way and through various adaptation and productivity pathways (Ariom *et al.,* 2022; Hansen *et al.,*2021; Tamru *et al.,* 2025).

4.8 Chapter Summary

This chapter presented and discussed the empirical findings on the role of weather and climate information services (WCIS) and climate-smart technologies (CSTs) in influencing common bean productivity among smallholder farmers in Homa Bay Town Sub-County. The results showed that the farming system was dominated by smallholder, experienced farmers, with gender, age, and education playing important roles in shaping access to resources, information, and decision-making. The findings further revealed a strong positive relationship between the intensity of CST adoption and bean productivity, with higher adoption levels associated with increased yields.

However, increased CST adoption intensity was also linked to greater yield variability, indicating that productivity gains depend on complementary factors such as farm conditions, farmer capacity, and effective use of WCIS. The chapter also highlighted the influence of farm characteristics, including land size and soil type, on the performance of climate-smart practices, emphasizing the need for context-specific interventions. Overall, the findings underscore the importance of integrating WCIS with climate-smart technologies to enhance decision-making, improve productivity, and strengthen resilience among smallholder farmers. The implications of these findings are discussed in the next chapter.

CHAPTER FIVE
CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The study concluded that climate-smart technologies (CSTs) had a statistically significant positive effect on productivity, as the null hypothesis (H_{01}) was rejected. The results suggested a significant difference in mean yield with increasing adoption intensity of the CSTs and supported the rejection of the null hypothesis that CSTs cannot help increase yield. The overall increase in yield variability at these higher adoption rates, as well as the small number of farmers in the highest adoption category, suggests that caution is warranted when interpreting the results. Also, CSTs intensity was correlated to adoption rates, rather than to the effectiveness of the specific combinations of technologies, and therefore was not used to identify an optimum combination of practices.

The study also found that in general, farmers had access to weather and climate information services (WCIS) and that the effects of WCIS on the uptake of climate-smart technologies were moderate. Informed decision-making was supported by WCIS, but it was not a catalyst for adoption. This was a partial rejection of the null hypothesis, which was limited by other factors such as limited financial resources, access to inputs and access to extension services, etc., which limited the farmers' ability to benefit from the climate information.

It was further revealed that the weather-informed practices (WIPs) had a significant positive effect on the productivity of common bean. Farmers using the climate information for decision-making stated their improved crop productivity and decreased risks in production. The results show that there is enough evidence to reject the null hypothesis; thus, WIPs are meaningful to improve farm productivity.

The study also showed that use of weather-informed practices had a significant effect on improving households' climate risk-resilience. Adopting climate information led to more stable production outcomes, better food security and greater ability to respond to climate variability for farmers who integrated climate information into their decision-making. It was therefore rejected, and the important role of WIPs in building household resilience confirmed.

The findings further suggest that a combination of weather and climate information services, weather-informed practices and climate-smart technologies provides greater benefits on both productivity and household resilience than any single climate adaptation strategy alone, further emphasizing the need for integrated approaches to the use of weather and climate information

5.2 Recommendations

5.2.1 Recommendations for policy

The study suggests the promotion of climate-smart technologies be implemented by methods that would encourage the adoption of more than one complementary technology since there was an association between the intensity of the adoption with productivity. Interventions must be adaptable, however, and context-dependent, as there was no best combination of technologies found in the findings. In supporting effective and sustained adoption, strengthening extension services, farmer training and provision of demonstration-based learning would be essential.

Weather and climate information and services should also be strengthened to be more accurate, timely and localized. There is a need for more linkages between the WCIS and extension systems to support the interpretation and application of the information by farmers. Meanwhile, access to credit, farm inputs, and technical assistance are structural issues that need to be tackled to help farmers put the information to use in making decisions.

The study also suggests to expand the application of weather informed practices in more farm management activities such as soil fertility management, pest and disease control and application of inputs. Improved take-up of these practices would help increase productivity and climate risk resilience of smallholder farmers.

Lastly, it is recommended to have integrated climate adaptation strategies led by weather and climate information services, climate-smart technologies and weather-informed practices supported by development partners and policy-makers. These integrated solutions work better to deal with the multifaceted issues of climate variability. Interventions need to be locally contextualized to remain inclusive, relevant and sustainable in the long term, based on local socio-economic and agro-ecological conditions.

5.2.2 Recommendations for Future Work

Future research should use longitudinal data to better establish causal relationships between WCIS, CSTs, weather-informed practices, and outcomes such as productivity and resilience. There is also a need to identify optimal combinations of climate-smart technologies, moving beyond adoption intensity to assess effectiveness. Additionally, studies should examine the barriers limiting the use of WCIS, including financial, institutional, and behavioral factors. Finally, further research in different agro-ecological contexts is recommended to improve the generalizability of findings.

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APPENDICES

Appendix I: Questionnaires

My name is Kalenya Millicent, a Master of Science student in Climate-Smart Agriculture at Muranga University of Technology. Together with KALRO, I am conducting a research project as follows: Effects of weather and climate- information services (WCIS) on adoption of climate-smart technologies and Bean productivity in Homa Bay Town Sub-County, Homa Bay County, Kenya.

The reason why you are being invited to participate is that you are a smallholder bean farmer who has been exposed to WCIS training. Interview will last approximately 45-60 minutes, and will be related to questions about your farming practices, application of climate information, and bean production.

Your involvement is at all voluntary. You have the option of not responding to any question or terminating the interview any time without penalty or any loss of services. Your choice will not have any implications on your access to the extension services, WCIS and your further support.

The interview will be in a respectful way and on a private basis. No report will contain your name and your answers will be kept confidential. Electronically, a secure data collection system will be utilized and data stored in password-protected devices with a limited number of users, which will only be the researcher and supervisors.

TITLE

Influence of weather and climate information services and climate-smart technologies on bean productivity and household resilience among smallholder farmers in Homa bay town sub-county, Kenya.

Section A: Farmer's General Information (Applies *to all respondents)*

Question	Response
1. Name of the farmer (Optional)	_____
2. Gender	☐ Male ☐ Female
3. Age (Years)	☐18-35 years ☐ 36-45 years ☐ 46-55 years ☐ Over 55 years
4. Ward	☐ Homa Bay Central ☐ Homa Bay West ☐ Homa Bay East ☐ Arujo
5. Level of Education	☐ None ☐ Primary ☐ Secondary ☐ College/University
6. Household size	☐ 1-5 members ☐ 5-10 members ☐ over 10 members
7. Primary source of household income	☐ Farming ☐ Business ☐ Employment ☐ Others (specify)
8. How many years have you been growing beans?	☐ less than 5 years ☐ 10-15 years ☐ over 15 years
9. Average size of plot under bean production in the last season	☐ Less than 1 acre ☐1-2 acres ☐ 2.1 acres- 5 acres ☐ Over 5 acres

10. How many plots of beans did you manage in the last season? _____

11. The type of soil of the plot under bean production ☐ Sandy soil ☐ Loamy soil ☐ Sandy loam soil ☐ Black cotton soil ☐ Other (specify)

Section B: Climate-Smart Technologies (CST) applied and their effects on bean productivity

(Quasi-experimental: CST adopters versus CST non-adopters)

12. Has this farmer ever been closely monitored after receiving WCIS training?

☐ Yes

☐ No

Section 1: Planting stage.

13. When did you plant your beans during the last season?

☐ Early (before the rain had started)

☐ AT the onset of rain

☐ Late (When the rain had already started)

14. What mainly guided your planting decision (when to plant)?

☐ Weather and climate information

☐ Personal experience

☐ Advice from extension officer/ farmer group

Other (Specify) _____

15. Which planting method did you use?

☐ Row planting

☐ Broadcasting

16. If row planting, how could you describe the spacing?

☐ Recommended spacing

☐ Wider than recommended

☐ Narrower than recommended

☐ Not sure

17. Which bean variety did you plant?

☐ Certified/ improved seed variety

☐ Local seed variety

☐ Both

SECTION 2: Soil Management/ input used

18. Did you apply any fertilizer?

☐ Yes

☐ No

19. If yes, which type of fertilizer did you apply?

☐ Organic manure

☐ DAP

☐ NPK

☐ Urea

Other (specify) _____

20. How would you describe the quantity of the fertilizer you applied?

☐ Less than recommended

☐ Recommended

☐ More than recommended

☐ Not sure

21. Why did you choose these inputs? _____

22. Did you mulch your bean plot?

☐ Yes

☐ No

23. If yes, which material did you use?

☐ Crop residues

☐ Grass

☐ Other (specify) _____

Section 3: Crop Management Practices

24**.** Did you weed your bean plot?

☐ Yes

☐ No

25. If yes, which weeding method did you use?

☐ Hand pulling

☐ Digging with hoe

☐ Use of herbicides

☐ Other (specify) _____

2. How many times did you weed your plot?

☐ Once

☐ Twice

☐ More than twice.

27. Did you hire labour during the last season?

☐ Yes

☐ No

28. If yes, how much was the cost? _____

29. Did you apply pesticides to your bean plot?

☐ Yes

☐ No

30. What was the rate of pest infestation?

☐ Low

☐ Moderate

☐ High

31. Did you apply chemicals to control diseases?

☐ Yes

☐ No

32. How serious was the disease issue?

☐ Low

☐ Moderate

☐ High

33. What were some of the diseases or pests you encountered? _____

Section 4: Experience of weather-related stress

34. Did you experience weather-related stress last season?

☐ Yes

☐ No

35. What was the common type of stress?

☐ Drought

☐ Floods

☐ Other (specify) _____

36. How did you respond to these conditions? _____

Section 5: Bean productivity

3. What size bean plot did you harvest during the last season in acres? _____

38. Approximately, how many kilograms of dry beans did you harvest during the last season? _____

39. How would you describe your last season's yield compared to previous seasons?

☐ Lower

☐ Constant

☐ Higher.

4. In your opinion, what influenced your bean yield during the last season? _____

Section 6: Adoption of CST

41. Did you apply climate-smart technologies in your bean plot during the last season?

☐ Yes

☐ No

42. If yes, which climate-smart technologies did you apply? (select all that apply)

☐ Certified/ improved seed variety

☐ Crop rotation

☐ Application of fertilizer/manure

☐ Mulching

☐ Raised beds

☐ Zai pits

☐ Improved pest/ disease management

☐ Other (specify) _____

43. Why did you apply the above-mentioned CSTs? (select all that apply)

☐ Increased Yield

☐ Reduces climate-related risks e.g. droughts

☐ Improves soil fertility ☐ Household food security

☐ High Incomes

☐ Reduces production costs

☐ Access to markets

☐ Conserves water

☐ Government Policy requirements to promote CSA

☐ Others (specify)

44. How many years have you been using these technologies?

☐ Less than 1 year

☐ 1-3 years

☐ Over 3 years

4. What benefits/ advantages have been gained due to the use of these climate-smart technologies? _____

46. What challenges have you experienced while using these climate-smart technologies? (select all that apply)

☐ High Input Costs

☐ Expensive CSTs

☐ Limited access to timely WCIS

☐ Lack of know-how on CSTs

☐ Inadequate Extension services

☐ High labour required for CSTs

☐ Lack of Credit Access

☐ Unpredictable markets/prices

☐ Crop failure risks ☐ Others (specify)

47. Are you currently classified as

☐ CST adopter (Applied at least one CST)

☐ CST non-adopter (applied less than one CST)

SECTION C: ACCESS AND USE OF WCIS AND INFLUENCE ON CST ADOPTION

48. Do you get any weather or climate forecasts (rainfall, temperature, droughts)?

☐ Yes

☐ No

49. If yes, what are your main sources of WCIS (select all that apply)

☐ Radio

☐ SMS

☐ Extension officer

☐ Farmer Group

☐ Television

☐ Mobile apps

☐ social media (WhatsApp, Facebook, Instagram)

☐ NGOs/ Projects

☐ Others (specify) _____

50.What is your frequency of getting this weather information?

☐ Daily

☐ Weekly

☐ Monthly

☐ Only before planting

☐ Rarely

51. How do you use weather information received while making farming decisions?

☐ Setting land preparation

☐Setting planting date

☐ Schedule when to apply fertilizer

☐ Schedule irrigation

☐ Pest/disease management

☐ Set the time to harvest

☐ Schedule irrigation ☐ Others (Specify)

52. How easy is it for you to understand the Weather Information / WCIS you receive?

☐ Very easy

☐ Easy

☐ Moderate

☐ Difficult

☐ Very difficult

53. Weather information/ WCIS help me decide the right time to plant beans

☐ Strongly agree

☐ Agree

☐ Neutral

☐ Disagree

☐ Strongly disagree

54. Weather information/WCIS help me choose the appropriate bean variety (drought resistant, certified, short maturity)

☐ Strongly agree

☐ Agree

☐ Neutral

☐ Disagree

☐ Strongly disagree

55. Weather Information/ WCIS help me determine when to apply fertilizer (Organic or inorganic)

☐ Strongly agree

☐ Agree

☐ Neutral

☐ Disagree

☐ Strongly disagree

56. Weather information /WCIS improves my planning for irrigation /water conservation

☐ Strongly agree

☐ Agree

☐ Neutral

☐ Disagree

☐ Strongly disagree

57. Weather information/WCIS help me minimize losses due to droughts, floods, outbreak of pests/diseases, post-harvest losses

☐ Strongly agree

☐ Agree

☐ Neutral

☐ Disagree

☐ Strongly disagree

58. What challenges do you face in accessing weather information/WCIS? (Select all that apply)

☐ Lack of mobile phone/ radio/tv

☐ High cost of weather information/WCIS

☐ Unreliable forecasts

☐ Irregular updates

☐ Information too technical to understand

☐ Lack of trust in providers of weather information

☐ Others (specify)

SECTION D: CONTRIBUTION OF WEATHER-AND CLIMATE-INFORMED PRACTICES ON BEAN PRODUCTIVITY

59. Have you been practising weather-informed and climate-informed practices in the last two seasons?

☐ Yes

☐ No

60. If yes, which practices? (select all as applicable)

☐ Adjusted planting date

☐ Use of certified seeds

☐ Use of short-term maturity varieties

☐ Schedule when to apply fertilizer

☐ Pest/ disease management

☐ Conservation of soil moisture

☐ set time when to harvest ☐ Others (specify)

61. How have the above selected practices affected your bean yield in comparison with when you were not practicing it?

☐ Much higher

☐ Slightly higher

☐ No change

☐ Slightly lower

☐ Much lower

☐ Others (specify) _____

62**.** Have you experienced lower losses of crops after implementing weather-informed practices?

☐ Yes

☐ No

63. If yes, how well have the practices enabled you to mitigate the losses that climate risks like floods and droughts have caused you?

☐ A little

☐ Moderate

☐ High

☐ Very high

64. In your opinion, which of the weather-and climate-informed practices has boosted your bean productivity and why? _____

SECTION E: CONTRIBUTION OF WEATHER-AND CLIMATE-INFORMED PRACTICES ON FARMERS' RESILIENCE

65. In the past 3 years, have you encountered any major climate-related risks such as drought, floods, outbreak of pests/diseases, invasive weeds?

☐ Yes

☐ No

66. If yes, what impact did it have on your bean production? Briefly explain _____

67. How did you cope with the loss?

☐ Replanting

☐ Irrigation

☐ Changing the seed variety

☐ Changing of the pests/ herbicides/weeds management methods

☐ Other (specify) _____

68. Weather information/WCIS enables me reduce crop losses due to drought or erratic rainfall.

☐ Strongly agree

☐ Agree

☐ Neutral

☐ Disagree

☐ Strongly disagree

69. Weather information/ WCIS help me use inputs (seeds, fertilizer, manure, mulches) more efficiently.

☐ Strongly agree

☐ Agree

☐ Neutral

☐ Disagree

☐ Strongly disagree

70.Weather information/ WCIS has improved my bean production and therefore, improved my household food security.

☐ Strongly agree

☐ Agree

☐ Neutral

☐ Disagree

☐ Strongly disagree

71. After using this weather information, do you now feel more confident to plan your farm activities and make decisions using these weather advisories?

☐ Yes

☐ No

72. What is your overall satisfaction with Weather information/ WCIS?

☐ Satisfied

☐ Very satisfied

☐ Neutral

☐ Dissatisfied

☐ Very dissatisfied

73. What improvements would make Weather information/ WCIS more useful for bean farmers? (Select all that apply)

☐ More localized forecasts

☐ More frequent updates

☐ Use of local language

☐ More training on how to use WCIS

☐ More affordable/free access to WCIS

☐ Use of trusted extension agents

☐ Integration with digital platforms (mobile Apps, social media)

☐ Other (specify)

SECTION F: CLOSING REMARKS

Enumerator to thank the farmer for his or her time.

Appendix 2: Approval for research

MURANG'A UNIVERSITY OF TECHNOLOGY
Office of the Director, Postgraduate Studies
E-mail: bps@mut.ac.ke
Website: www.mut.ac.ke
P.O. Box 75-10200
Murang'a, Kenya

Ref: MUT/ARP/PGS/19/2020 /VOL.1 **Date:** 5th May, 2026

Ms. Millicent Kalenya – GR401/5182/2023,
School of Agriculture and Environmental Sciences,
Murang'a University of Technology,
P.O. Box 75-10,200
Murang'a.

Dear Ms. Kalenya,

RE: APPROVAL OF RESEARCH PROPOSAL AND SUPERVISORS.

I am pleased to inform you that the Directorate of Postgraduate Studies on 23rd April, 2026 considered and approved your Master research proposal entitled ***"Influence of Weather and Climate Information on Adoption of Climate-Smart Technologies and Bean Productivity in Homabay County, Kenya."*** and appointed the following as supervisors:

1. Dr. Charles Orek - Murang'a University of Technology

2. Prof. Dorothy Amwata - Murang'a University of Technology

You may now proceed with your collection subject to obtaining research permit from NACOSTI, if required. You should also begin consulting your supervisors and submit through them quarterly progress reports to the Director Postgraduate Studies through your CoD and School Dean. Progress Reports forms can be accessed in the Student Portal.

It is the policy and regulations of the University that you observe deadlines. The guidelines on Postgraduate supervision can be accessed in the post graduate Handbook.

Your responsibilities as a student will include, among others;

i. Maintain regular consultation with your supervisor(s), at least once a month
ii. Submit quarterly reports on time, through your supervisors, CoD, Dean and to the Director of Postgraduate Studies;

iii. Ensure quality work all through;
iv. Present your research findings at 2-3 seminars/conferences prior to thesis examination.
v. Publish one article from your research findings in a refereed journal prior to thesis examination.

For any further clarification please contact the undersigned.

Yours Sincerely,

Prof. Geoffrey Muchiri, PhD
Director, Postgraduate Studies
GM/MMK

DIRECTORATE OF POSTGRADUATE STUDIES
MURANG'A UNIVERSITY OF TECHNOLOGY
05 MAY 2026
P. O. Box 75 - 10200, MURANG'A
Tel: 0771463515, Email: info@mut.ac.ke

Copy to:
1. Registrar, Academics, Research and Students Affairs
2. Dean, School of Agriculture and Environmental Sciences

Appendix 3: Nacosti permit

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Ref No: **523149**

Date of Issue: **06/March/2026**

RESEARCH LICENSE



This is to Certify that Ms.. MILLICENT KALENYA of Murang'a University of Technology, has been licensed to conduct research as per the provision of the Science, Technology and Innovation Act, 2013 (Rev.2014) in Homabay on the topic: INFLUENCE OF WEATHER AND CLIMATE INFORMATION SERVICES ON ADOPTION OF CLIMATE-SMART TECHNOLOGIES AND BEAN PRODUCTIVITY IN HOMA BAY, COUNTY, KENYA. for the period ending : 06/March/2027.

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See overleaf for conditions

Appendix 4: Publications

This thesis has produced the following publication:

Kalenya, M., Orek, C., Amwata, D., Kagabo, D., & Ngige, C. (2026). Influence of Weather and Climate Information Services and Climate-Smart Technologies on Common Bean Productivity and Household Resilience in Homa Bay County, Kenya. *African Journal of Climate Change and Resource Sustainability*, *5*(1), 434–457. https://doi.org/10.37284/ajccrs.5.1.5188