UNIVERSITY OF NAIROBI

CLIMATE-SMART AGRICULTURE OPTIONS FOR ENHANCED RESILIENCE AND FOOD SECURITY: A CASE STUDY OF YATTA, MACHAKOS COUNTY, KENYA

BY

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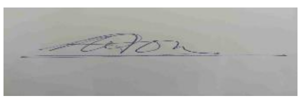

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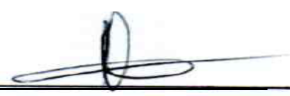

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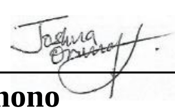

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DECLARATION

I hereby declare that this thesis titled "Climate-Smart Agriculture (CSA) Options for Enhanced Resilience and Food Security in Yatta, Machakos County, Kenya" is my original work and has not been submitted for a degree in any other University.

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DEDICATION

To my husband (Dr. Titus N. Mwanthi), my son (Joel) and daughter (Brilliant); your encouragement through 'push and pull' has made this journey successful, to my dear mum Beatrice and my late dad Moses Kalele; I owe my success to your hard work and inspiration.

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ABSTRACT

The Kenya's agriculture sector is key for rural livelihoods though highly impacted by climate change. The agriculture is mostly rainfed and dominated by smallholder farmers which increases vulnerability to climate variability and change impacts. There is need to enhance farmers' resilience to climate change as well as strengthen their adaptive capacity through transition to sustainable farming practices. The overall objective of this study was to investigate selected climate-smart agriculture (CSA) options that can be integrated in smallholder farming systems for enhanced resilience and food security in Yatta sub-County, Machakos County. The study sought to establish rainfall and temperature trends during the analysis period (1983-2014) and relate the trends with crop yield to determine their relationship. The study investigated farmers' perceptions to climate change and variability and the on-farm adaptation strategies they had adopted. Based on the climate trends and farmers' perceptions of climate change the study sought to integrate selected climate-smart agriculture (CSA) models (conservation agriculture and Zai pits) into farmers' practices to evaluate the impact of the models on crop yield in comparison to conventional farming practice. The study adopted a mixed methodology approach which integrated qualitative and quantitative research methods. Both primary and secondary data was used. Primary data was obtained using structured questionnaire, focus group discussions and experiments while secondary data (climate and crop) was obtained from existing databases. Climatic data were analyzed using descriptive and trend analysis. Detection of statistically significant climate trends was done using parametric (linear regression) and non-parametric (Mann-Kendall test), standard precipitation index and moving averages. Multiple regression model was used to analyze relationship between crop yield and climate variables. The data from the questionnaire was analyzed using descriptive and chi-square statistics. Quantitative statistics were used to analyze the experimental data using analysis of variance. The Mann-Kendall test revealed statistically significant ($P<0.05$) trends for the annual and seasonal rainfall. The linear regression showed increasing trends in annual temperature which supported farmers' perceptions with majority farmers reporting increasing daytime temperatures (79%) and number of hot days (65%) over the last five years. However, the regression analysis showed increasing rainfall trends contrary to farmers' perceptions of decreasing seasonal and annual rainfall trends Annual-monthly rainfall variation showed a bimodal rainfall with two distinct rainfall seasons in a year, however the monthly rainfall trends were not statistically significant ($P>0.05$. There was a significant direct correlation between crop yield and rainfall and temperature trends. Although farmers had adopted several on-farm adaptation strategies, the adoption levels remained low. Water management strategies (water conservation and water harvesting) recorded higher adoption rates of 62.71% and 53.95% respectively. The tested CSA options proved their potential towards increasing crop yield in comparison to the conventional practices. The occurrence of climate change events in the study area has affected agriculture productivity, food security and socio-economic status of the households. Integration of the CSA into smallholder farming systems is a viable option towards attaining food security and increased resilience to CC impacts.

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LIST OF ABBREVIATIONS/ACRONYMS/SYMBOLS

ACP	Caribbean and Pacific countries
ADBG	Africa Development Bank Group
AMAL	Agriculture, Marketing, Access and Linkages
ANOVA	Analysis of Variance
AR5	IPCC Fifth Assessment Report
ASALs	Arid and Semi-arid Lands
ASDSP	Agricultural Sector Development Programme
CA	Conservation Agriculture
CA-SARD	Conservation Agriculture for Sustainable Agriculture and Rural Development
CBOs	Community Based Organization
CDF	Constituency Development Fund
CGA	Cereal Growers Association
CIDP	County Integrated Development Plan
CIM	Christian Impact Mission
CIMMYT	International Maize and Wheat Improvement Center
CO_2	Carbon dioxide
CSA	Climate Smart Agriculture
CV	Coefficient of Variation
CVT	Conventional Tillage
DEAP	Machakos District Environment Action Plan
DPP	Directorate Plant Production
FAO	Food and Agriculture Organization of the United Nations
FAW	Fall Army Worm
FGDs	Focus Group Discussions
FYM	Farm Yard Manure
GAP	Good Agricultural Practices
GCM	Global Climate Models
GeoCLIM	Geospatial Climate Data management and analysis software
GDP	Gross Domestic Product

GHA	Greater Horn of Africa
GHGs	Green House Gases
GOK	Government of Kenya
HIV	Human Immunodeficiency Virus
IAASTD	International Assessment of Agricultural Knowledge, Science and Technology for Development
ICPAC	IGAD Climate Prediction and Applications Centre
ICRAF	International Centre for Research in Agro-forestry
IFAD	International Fund for Agricultural Development
IITA	International Institute of Tropical Agriculture
IPCC	Intergovernmental Panel on Climate Change
KALRO	Kenya Agricultural and Livestock Research Organization
KARI	Kenya Agricultural Research Institute
KDFP	Kenya Dryland Farming Project
KMD	Kenya Meteorological Department
KNBS	Kenya National Bureau of Statistics
KNMI	Royal Netherlands Meteorological Institute
KV2030	Kenya Vision 2030
MAM	March-April-May
MK	Mann-Kendal
MLN	Maize Lethal Necrosis
MLND	Maize Lethal Necrosis Disease
NEMA	National Environment Management Authority
NGOs	Non-governmental Organizations
OECD	Organization for Economic Cooperation and Development
OND	October-November-December
PAL	Participatory Action Learning
ROK	Republic of Kenya
SASOL	Sahelian Solution Foundation
SAT	Semi-Arid Tropics
SCC-Vi	Swedish Co-operative Centre and Vi Agroforestry

SDGs	Sustainable Development Goals
SOC	Soil Organic Carbon
SPSS	Statistical Package for Social Scientists
SSA	Sub-Saharan Africa
SWC	Soil-Water Conservation
T_{max}	Maximum Temperature
T_{min}	Minimum Temperature
ToTs	Trainers of Trainers
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
UNICEF	United Nations Children's Fund
USAID	United States Agency for International Development
USAID- MEA	United States Agency for International Development Millennium Ecosystems Assessment
VIF	Variance Inflation Factor
WFP	World Food Programme
WHO	World Health Organization
WMO	World Meteorological Organization

GLOSSARY OF TERMS

Adaptation: Adjustment in ecological, social or economic system in response to actual or expected climatic stimuli and their effects to moderate or offset potential damage or take advantage of opportunities associated with change in climate.

Adaptive capacity: This is the ability of a system to adjust its characteristics in order to expand its range under existing climate variability and future climate change.

Climate change: Climate change is a significant change in the statistical distribution of weather patterns over periods ranging from decades to millions of years. Climate change may be a change in average weather conditions, or in the distribution of weather around the average conditions (i.e., more or fewer extreme weather events)

Climate variability: Refers to variations in the mean state and other statistics (such as standard deviation, occurrence of extremes, and others) of climate at all spatial and temporal scales beyond that of individual weather events.

Dry lands: Refers to all terrestrial regions where the production of crops, forage, wood and other ecosystem services is limited by water, which encompass all lands where climate is classified as dry-sub-humid (aridity index 0.50-0.65), semi-arid (aridity index 0.20-0.50) and arid (aridity index 0.05-0.20).

Exposure: This is used to refer to the presence (location) of people, livelihoods, environmental services and resources, infrastructure, or economic, social, or cultural assets in places that could be adversely affected by physical events and which, thereby, are subject to potential future harm, loss or damage.

Extreme events: Refers to the occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends ('tails') of the range of observed values of the variable.

Food security: A situation that exists when people have secure access to sufficient amount of safe and nutritious food for normal growth, development and an active and healthy life. Food insecurity may be caused by the unavailability of food, insufficient purchasing power, inappropriate distribution, or inadequate use of food at the household level.

Greenhouse gas (GHG): Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere, and the clouds.

Gross Domestic Product: Gross Domestic Product (GDP) is the monetary value of all goods and services produced within a nation.

Multi-stage sampling: A sampling technique in which samples are selected in a sequence of stages, each sample being drawn from within the previously selected sample.

Mitigation: Climate change mitigation refers to efforts to reduce or prevent emission of greenhouse gases.

Perception: It is the process by which we receive information or stimuli from our environment and transform it into psychological awareness.

Purposive sampling: A non-probability sampling method by which groups are selected for interview according to the researchers' choice. The method value lies in selecting information-rich cases for in-depth analysis related to the issue being studied.

Resilience: The ability of a system to anticipate, absorb, accommodate or recover from the effect of a hazardous event in a timely and efficient manner, including through ensuring preservation, restoration, or improvement of its essential/basic structures and functions.

Risk: This refers to the interaction of physically defined hazards with the properties of the exposed systems. Risk equals the probability of climate hazard multiplied by a given system's vulnerability.

Simple random sampling: A technique where there is an equal chance of each member of the population to get selected to form a sample.

Tilling: Preparing and cultivating land for planting crops.

Triangulation: Involves the practice of viewing things from more than one perspective. This can mean the use of different methods, different sources of data or even different researchers within a study.

Vulnerability: The degree to which a system is susceptible to, and unable to cope with adverse effect of climate change including climate variability and extremes.

Insitu datasets: Any data/observation taken by an instrument in direct contact with the medium it "senses".

CHAPTER ONE: INTRODUCTION

1.1 Background information

Agriculture sector is a focal economic pillar for most of the developing World and a prime contributor to the gross domestic product (GDP). The agriculture sector accounts for about a third of Africa's GDP contributing an average of 21% and ranging from 10% to 70% of GDP while creating employment for about 65 percent of the workforce (USAID, 2003, IPCC, 2007a). The sector is a source of livelihood for majority of rural poor households in Africa who depend directly or indirectly on agriculture (FAO, 2015). However, the sector is faced with a number of biotic and abiotic challenges in which climate variability and change has become one of the major abiotic impediments to agriculture and food security in Sub-Saharan Africa (SSA) (Mutimba *et al*., 2010). A report by the Intergovernmental Panel on Climate Change (IPCC) indicates that agricultural production in most of the African countries is threatened by impacts posed by climate change thus affecting the rural livelihoods that are dependent on agriculture. The report further outlines that most of the agricultural area in the arid and semi-arid lands (ASALs) is expected to decrease as well as duration of growing season and potential of crop yield which will ultimately impact on crop production (IPCC, 2007a). A report by FAO (2016), states that effects of changes in climate that are already being felt pose a major risk to global food security and could seriously compromise the prospective of agriculture to feed the rural poor and most vulnerable thus impeding advancement towards global eradication poverty, hunger, and malnutrition.

Food Security is one of major elements of achieving sustainable development and poverty alleviation and has been a key goal of many international, regional and national organizations especially in the developing countries. Food security has been defined as a measure of an individual's ability to access nutritious and sufficient amount of food. "A state of food security occurs when all people, at all times, have physical and economic access to adequate, safe and nutritious food that is able to meet their dietary requirements and food preferences for an active and healthy life" (FAO, 2009). Efficient food system is a necessary element towards positive contribution to all dimensions of food security which are food availability, food accessibility, food utilization and stability (FAO, 2009). The adoption of the 2030 Agenda for Sustainable Development is a global vision which guides nations' commitment to transform the world through eradicating poverty and realization of sustainable development by the year 2030. The sustainable development goal (SDG2) requires all countries to work towards eliminating hunger, realizing national food security, enhancing nutrition and promoting sustainable agriculture by the year 2030. A study was conducted recently to monitor the progress of implementation of the SDGs in achieving a World free of hunger and malnutrition. The monitoring report states that "although there has been a subsequent to a prolonged decline, World hunger seems to have risen again with food security situation worsening in parts of SSA and South Eastern and Western Asia". The report further indicates that "the number of undernourished people in the World had increased in the year 2016 to an estimated 815 million up from 777 million recorded in 2015, although this was a slight drop from about 900 million in the year 2000" (FAO, IFAD, UNICEF, WFP and WHO, 2017).

A report on World population projections showed that global population is estimated to surpass 9 billion people by the year 2050 from a current 7 billion population (UNESCO, 2012). According to World Bank (2013), the SSA will experience more increase in its population where it is projected to increase from around one billion in 2010 to up to around 1.9 and 2.4 billion people in 2015. According to estimates by FAO, there is need to increase annual crop and livestock production to 60% higher than it was in 2006 which would aid to meet food demand for the rapidly growing World population (FAO, 2016). About 80% of the requisite boost in crop production will have to come from increased crop yields and 10% from enhanced number of cropping seasons per year. However, the potential for yield increase is greatly hindered by widespread land degradation and increasing water shortage (Alexandratos and Bruinsma, 2012). Additionally, variability and change in climate is already impacting production, with diminishing crop production and increased variability of crop yield as some of the consequences being experienced in some areas. These impacts are mostly affecting smallholder farmers who are the main producers, depend on rainfed agriculture leading to increased vulnerability and have limited means to adapt to the changing climate (FAO, WFP and IFAD, 2012). To achieve sustainable food production and improved livelihoods for the rural poor, calls for an urgent transformation of agriculture to productive and sustainable agriculture that will support resilience and adaptive capacity of smallholder farmers' to impacts of changing climate (World Bank, 2008; FAO, 2016).

In Kenya, the agriculture sector contributes 52% to the country's GDP with a direct and indirect contribution of about 27% and 25.4% respectively through linkages to the service sector and agro-based industries (FAO, 2015). The sector is a major source of livelihood to three-quarters of the Kenyan population providing eighteen percent (18%) of formal and sixty percent (60%) of total employment respectively and thus it's very fundamental for sustainable development and poverty reduction (ADBG, 2014). The sector is a priority in the Kenya Vision 2030 (KV 2030), and is anchored in the economic pillar which seeks to bring out a creative, commercially oriented and contemporary agricultural sector through institutional reforms, enhanced productivity, land use revolution, value addition to agricultural products, better market access and growth of ASALs (GOK, 2007). The Kenyan Agricultural Sector Development Strategy (ASDS) 2010-2020 consists of a detailed plan which looks forward to promoting the Kenyan agricultural sector to become a vital driver for delivering the ten per cent (10%) annual economic growth rate which has been visualized under the economic pillar of the KV 2030 (GOK, 2010). Besides achieving nutritional and food security for all Kenyans, the strategy also aspires at empowering rural communities through income generation as well as creation of employment opportunities.

Food security is one of the themes of the current Kenyan President transformative agenda 'The Big Four Agenda' which aims at enhancing development. The three pillars and outcomes of the Agenda include; transforming lives, transforming societies and transforming the nation. Approximately 98% of Kenya's agriculture is rainfed and depends entirely on the bimodal rainfall pattern which implies that the farming systems are extremely vulnerable to the changing rainfall patterns, droughts and increasing temperatures trends (UNEP, 2009). However, only 16% of Kenya's land receives sufficient and consistent rainfall and thus considered suitable for production with high and medium agricultural potential. The remaining 84% of the land has been classified as arid or semi-arid with annual rainfall average of 400mm which is not suitable for rainfed agriculture due to inadequate and unpredictable rainfall patterns. Although there is ample land, in most cases farmers grow crops that are not suitable for this rainfall regime or for the type of soils. Additionally, the frequency in the occurrence of droughts has increased with crop failure being experienced in one out of every three seasons. There is an increase in vulnerability of smallholder farming systems to climatic changes due to reliance on rain-fed agriculture coupled with limited knowledge and poor farming practices which has subjected rural households to continuous food insecurity, poverty and malnutrition.

To realize Kenya's agricultural productivity in the midst of changing weather conditions, there is need to implement sustainable adaptation strategies with careful selection of farm enterprises and incorporation of innovative measures into farmers' practices. There is also need to facilitate research-extension-farmer linkages and use of improved and latest technologies while transiting to climate-smart agriculture (CSA) technologies that would increase resilience and cushion farmers against adverse impacts of climate variability and change. Future research should be well structured to include participatory approaches which support integration of farmers into the research process for easier and sustainable adoption of innovations by smallholder farmers. It is in this scope that this research sought to investigate the potential of selected CSA models that could be integrated into smallholder farmers' practices for enhancing food security and resilience in Yatta Sub-County, Machakos County, Kenya.

According to FAO (2013), "CSA is referred to agriculture with the potential to increase productivity in a sustainable way, improve farmers' resilience, reduce or eliminate greenhouse gases, and improve realization of national food security and development goals". Another definition by McCarthy and Brubaker (2014) states that "CSA consists of a set of three central principles which entail increasing agricultural productivity in a sustainable way and farmers' incomes; improving farmers' resilience and adaptation to climate change. This includes increasing farmers' ability to adapt in the short-term in cases of added uncertainty over climate extremes; and in the medium-long term, as climate patterns become more apparent (Cooper *et al*., 2013); and where possible, reducing and/or removing GHG emissions, relative to business-as-usual practices". "CSA has shown the potential to offer 'triple-win' benefits for increased adaptation, productivity, and mitigation, providing a possible strategy to deal with both food security and climate change concerns".

1.2 Problem statement

An assessment on climate variability and change for the semi-arid Eastern part of Kenya showed that variations in temperature and rainfall data in seasonal and inter-annual timescales were being experienced in the region over time (Funk et al., 2010). "The assessment indicated that both mean minimum (T_{min}) and maximum (T_{max}) temperature had a high inter-annual variation, with T_{max} increasing significantly during the analysis period of 31years" (Funk *et al*., 2010). Continuous seasonal rainfall variability has led to highly inconsistent crop yield levels thus making agriculture to be considered as a non-viable livelihood option to vulnerable farming households (Cooper, *et al.*, 2008). In Machakos County, most farmers are small scale farmers whose livelihoods depend mostly on rain-fed agriculture and have over time reported frequent crop failures (GOK, 2013).

A study by Mburu *et al*. (2014) established that most people in Yatta sub-County were food insecure with 81.3% of the farmers indicating that they lacked enough food and only 0.6% indicating to have had sufficient food. The findings on the key sources of food shortage showed that changes in weather patterns was leading (94.2%) followed by poor farming methods (50.6%) (Mburu *et al*., 2014). Negative consequences of climatic changes have been experienced in farmers' agricultural systems with indicators including frequent droughts and famine, erratic and unreliable rainfall, disappearance of natural water sources mainly streams, frostbites, low crop yields, and pest infestations (Mburu *et al*., 2014; Gichangi *et al*., 2015) . Nevertheless, some farmers in the area have not made effort to adopt newly developed crop varieties or change their farming systems to suit the changing climate (Mburu *et al*., 2015; Agesa *et al*., 2019). Instead, they have continued with the conventional tillage (CVT) practices which lead to soil depletion and decreased soil fertility hence leading to persistent low crop productivity (Mburu *et al*., 2015; Gichangi and Gatheru (2018)). The main reasons why farmers have not adjusted their farming systems may be attributed to inadequate information which may be linked to inadequate extension services and also lack of incentives to adopt the new technologies.

The study considered that successful farmers' adaptation requires location-specific data on which adaptation practices work better and the rate of adoption but this information was not yet available for the study area. The study further took cognizant that informing successful adaptation policies calls for a better understanding of farmers' perceptions on climate changes, their adaptation strategies, the extent of adoption of the adaptation strategies and the relevance of the strategies in enhancing farmers' ability to cope with the climate change impacts. The study therefore sought to investigate climate changes and impacts experienced in Yatta and establish if the changes had affected crop production and farmers' livelihoods. Further, the study aimed to establish farmers' perceptions to climate change and their adaptation strategies. The knowledge and insights gained will guide on the climate-smart agriculture options with the potential to enhance smallholder farmers' food security and resilience. The study worked on the hypothesis that adoption of climate-smart agriculture technologies by smallholder farmers would increase their crop production as compared to the conventional farming methods.

1.3 Research Questions

The study sought to answer the following research questions:

1. Is there evidence of climate variability and change in Yatta Sub-County?
2. How do smallholder farmers in Yatta Sub-County perceive climate variability and change?
3. What are the effects of climate variability and change on crop yield in Yatta Sub-County?
4. How are smallhoder farmers in Yatta Sub-County adapting their agricultural practices to a varying and changing climate?
5. How effective is adoption of conservation agriculture zaipits in enhancing crop yield in Yatta Sub-County?

1.4 Study Objectives

*1.4.1 **Main objective***

The overall objective was to investigate selected climate-smart agriculture options that can be integrated in smallholder farming systems for enhanced resilience and food security in Yatta sub-County, Machakos County.

1.4.2 ***Specific objectives***

1. Analyze rainfall and temperature trends in Yatta Sub-County for 31 years;
2. Explore smallholder farmers' perceptions on climate variability and change in Yatta Sub-County;
3. Establish the effects of climate variability and change on maize and beans yield in Yatta Sub-County;
4. Examine smallholder farmers' adaptation strategies to climate variability and change in Yatta Sub-County; and
5. Investigate the impact of conservation agriculture and zai pits on maize and green gram yield in Yatta Sub-County.

1.5 Justification for the Research

Most of the communities living in the Kenyan ASALs are mainly dominated by pastoralists and smallholder farmers who depend on climate sensitive livelihoods leading to their increased susceptibility to the changing climate (Fraser *et al*., 2011. Information on historical climatic trends is thus important especially in the ASALs where rainfall and temperature is becoming increasingly unpredictable. Several studies have been conducted to appraise long-term climatic trends in ASALs areas in Kenya and how farmers perceive the observed changes in their surroundings (Cooper, *et al*. (2008); Gichangi *et al*. (2015); Gichangi and Gatheru (2018); Filho *et al*. (2017). Further studies have also tried to establish the effect of climate variability and change on household food security (Morton, 2007; Ekpoh, 2010; Mburu *et al.*, 2014). There is limited literature on any quantitative analysis that has been done to establish how climate variables relate with crop yield. Some of the findings indicate that climate in the ASALs has been changing over time with noted impacts on household food security and farmers' have perceived these changes. In spite of these findings, little information is available on what changes farmers have incorporated into their farming practices in order to cope with the changing weather patterns.

Although several studies have been done to explore adaptation strategies that farmers' have adopted in their farming practices to avert the changing climate, there are no records to show the extent to which the adaptation strategies had improved farmers ability to deal with the experienced climatic changes. This research intended to address this gap by focusing on farmers' adaptation to crop, water and soil management strategies and establishing extent to which the adaptation strategies had enhanced their ability to cope with climatic changes experienced in their farming systems. Finally, even though suggestions have been made on the sustainable farming models which farmers in ASALs should adopt to enhance their crop production, sufficient quantitative data to show why these models should be adopted versus CVT practices is lacking. This study was thus undertaken to address the gaps noted from previous research by generating climatic trends for the study area. The study analyzed the impact of the climatic trends on maize and beans yields which aided in adaptation planning for the smallholder farming systems to deal with extreme climate conditions. The study explored smallholder farmers' perceptions of climatic change and compared the perceptions with historical climate trends and also identified if the farmers had adjusted their farming systems to suit the changing weather patterns. Finally, the study aimed to support farmers' adaptation and response to experienced change by testing selected climate-smart farming options which could be integrated into smallholder farming practices for enhanced crop yield hence solving the challenge of food in-security.

1.6 Significance of the Research

The study aided in empowerment and transformation of households towards food security, reduced malnutrition and poverty levels. Data obtained on the benefits of the tested climate-smart agriculture models will be useful for replication in other farming systems experiencing similar challenges (changing weather patterns, declining soil fertility and low adoption of sustainable farming methods) and where similar models could be applied. The scientific data generated has been published in order to enhance its accessibility for use by other researchers and academia undertaking related studies in the ASALs.

The results from this study will add to the body of existing knowledge and will benefit scholars, students, government and research institutions that will integrate the knowledge and skills acquired to empower and impact other users. The lessons acquired from the study will aid in development, adoption and implementation of policies on climate-smart agriculture both at local, national and international context. Additionally, it is envisaged use of a Participatory Action Learning (PAL) approach, will enhance farmers' acceptance and adoption of the tested CSA practices (Zaipits and conservation agriculture) which would enhance sustainability and usefulness of the benefits acquired.

1.7 Scope of the study

The study was undertaken in selected villages in Yatta sub-County, Machakos County. The study adopted a PAL approach by integrating selected smallholder farmers and relevant stakeholders into the research process. The study aimed to investigate the potential of climate-smart agriculture practices (conservation agriculture and Zaipits) on maize and greengram yield when compared to conventional farming practice. The study analyzed climate data (temperature and rainfall) over a 31-year period to establish climatic trends to verify if climate change and variability was obvious in the research area. It also analyzed the relationship of the climatic trends had impacted crop yield for maize and beans over the 30-year period. Lastly the study explored farmers' perceptions of climate change and its indicators and what coping and adaptation strategies farmers had adopted in their farms to deal with the experienced changes.

1.8 Limitations of the Study

The climate trend analysis was limited to only 31 years (1983-2014) of climate data while the geographical location of the weather station was some considerable distance from the study area. The crop yield results are based on weather parameters (rainfall and temperature) while other factors affecting crop growth such as type of soils was not considered. Analysis of the impact of CSA models on crop yield did not take into account growth stages and physiological aspects of the test crops.

1.9 Overview of the methodological approach

The study adopted a mixed methods approach which integrated qualitative and quantitative research methods. Mugenda (2003), states that "qualitative research is useful for collecting data and explain phenomena in an elaborate manner and is effective in managing social issues that affect the society. It includes helps to give insight into events as well as create detailed descriptions of social realities and do not result to discrete numerical data while quantitative research predicts cause-effect hypotheses about social reality and its results are in form of discrete numerical or quantifiable data". Mugenda (2003) further states that "combination of different methods is useful since the methods supplement each other. Whereas qualitative approach helps in getting in-depth understanding, quantitative methods provide numerical data for achieving specific objectives and testing hypotheses. Thus use of both quantitative and qualitative research methods helped to avoid bias which could arise in using only one approach.

The research collected both primary and secondary data. Literature review and desk review was used to compliment collection of data and primary information sources. The primary data was obtained using structured household surveys, Focus Group Discussions (FGDs), and experiments. On the other hand, secondary data was obtained from existing databases from key government institutions as well as reviewing existing literature from peer-reviewed journals, books, published and unpublished scientific articles, assessment and policy reports. Demographic records, census data and reports from local administration were used to understand history of the households as well as social and economic structures of the community. A thorough literature review was conducted to understand climatic, socioeconomic dynamics and major policies that have had an influence on ASALs farming communities. Additionally, information from the study site, pertinent studies and literature from places outside the study site with similar ecological conditions was considered to provide valuable information. The review also focused on other studies conducted previously in the study area to obtain solid background information and a general context of the study site. This also aided in revealing what is already known and thus was useful in identifying research gaps that this study needed to address. An elaborative description of data that was collected using the both approaches is outlined in Chapter 3 Section 3.3.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter identified relevant literature in the past including other empirical studies related to the study. It sought to establish what others have said about the subject under study and what gaps are there in the literature. Literature review serves a very important role in informing the researcher what kind of data or information exists in regard to a particular area of study. The research was thus conducted with guidance by what already exists in literature.

2.2 An overview of climate variability and change

According to IPCC (2014c) "The causes to climate change have been attributed to the intensification in emissions of anthropogenic greenhouse gases (GHGs) as well as heat trapping gases (HTPs) which has been happening since the pre-industrial era mainly due to industrialization and increase in population. The increased accumulation of these gases into the atmosphere has led to excess heating which has resulted to climate change. IPCC (2014a) indicates that "persistent emission of GHGs will amplify warming and long-lasting changes in all components of the climate system, which will lead to increased likelihood of severe, persistent and irretrievable impacts to people and ecosystem. To reduce threats posed by the changing climate there is need for significant and continuous reductions in GHGs emissions which will have to be integrated with adaptation to realize substantial benefits". Many aspects of people and the ecosystem including human health, aquatic life, forests, agriculture, fresh water supplies and coastlines are already being affected by climate change (IPCC, 2001). Some of the climate change impacts that are already evident include rise in sea levels, more extreme heating events, melting of snow and ice, rampant outbreak of fires, flooding, changes in precipitation/rainfall, increasing periods of droughts, famine and diseases and changes in seasons (IPCC, 2014d).

2.2.1. Observed and Projected Trends in Global Climate

The IPCC forecasts have shown that Africa region will certainly be the most affected by changes in climate due to increased inconsistency and deviation in mean rainfall and temperature (IPCC, 2007a). The forecasts further show that there is a shift in both short and long term trends of rainfall and temperature parameters which calls for an understanding of the trends especially in the ASALs where the parameters are becoming increasingly unpredictable. The persistent rise in temperatures and changes in rainfall will hurt natural and agricultural systems in many ways especially through increased shortage of water, shortened and changes in growing seasons in some areas and increase in extent and occurrence of floods (IPCC, 2007b). A recent assessment by IPCC (2018) shows that risks associated with the continued increase in temperature will be more devastating in the Sub-Saharan Africa especially in countries like Kenya which lie along the equator

2.2.2. Observed and Projected Trends in Temperature

According to a report by the IPCC (2014b), "the climate system has warmed up expeditiously over the last two decades." The report further states that since 1950, each of the last three decades has sequentially been warmer compared to any preceding decade. WMO (2013) indicates that the warmest decade ever recorded since the beginning of modern weather measurements around 1850 was the 2001-2010. According to WMO (2014), the global mean near surface temperature for the year 2014 was comparable to the warmest years in the 165-year instrumental record. The global mean temperature for the year 2014 was 0.57 ±0.09^{o}C above the 1961-1990 global mean of 14^{o}C. It was 0.08^{o}C above the mean anomaly of 0.50^{o}C for the period 2005-2014: nominally placing 2014 as the warmest year on record (WMO, 2014). Global air temperature has been documented to increase by 0.85^{o}C during the period 1880 to 2012 (Zhang *et al*., 2015).

Several reports have implicated an increase in temperature trends in Africa since 1960s with significant increases recorded in the last five decades in different parts of East Africa (Niang *et al*., 2014). According to Engelbrecht *et al*. (2015), the near surface temperature in most African regions has shown an increase by ≥ 0.5°C during the last 50-100 years, with T_{min} increasing more rapidly than T_{max}. Additionally, *King'uyu et al*. (2000) established in some parts of East Africa, T_{min} had warmed by up to 0.6°C during the period 1939 - 1992. Moreover, a warming trend has been reported in the Greater Horn of Africa (GHA) particularly for the T_{min} (night-time) temperature (Omondi *et al*., 2014). Increasing trends in T_{max} during the period 1978 – 2004 have also been recorded for western Kenya highlands (Kericho) Wandiga *et al*. (2010).

An assessment of climate change and variability in the semi-arid part of Eastern Kenya showed that there have been discrepancies in seasonal and inter-annual rainfall and temperature data over time (Funk *et al*., 2010). From the assessment it was evident that there is an increase in year-to-year variation in both mean annual T_{min} and T_{max} with a notable increase in T_{max} for the period of 31 years (Funk *et al*., 2010). Results from a similar analysis which was conducted for Katumani weather station in Machakos showed that there was a high year-to-year variation in annual mean T_{max} and T_{min} over 31-year period. Results obtained from this analysis showed a general increase of 1^{o}C and 0.3^{o}C for maximum temperature and minimum temperature respectively which concur with the IPCC temperature projections for Eastern Africa (Gichangi *et al*., 2015).

2.2.3 Observed and Projected Trends in Rainfall

A report by IPCC (2014b) indicates that rainfall has been considered to be uncertain at global, regional or local scales over short periods. The report further states that there has been inconsistency in observed and modelled trends of rainfall due to high temporal and spatial variability. Cubasch *et al*. (2013), points out that trends in mean rainfall have been increasing globally since 1901 with decreased rainfall trends been noted in the tropics over the period 1901-2008.

Rainfall has become highly variable and more uncertain across Africa with notable spatial and temporal variations as well as decreased rainfall amounts been reported over the last three decades, with a likelihood that extreme rainfall variability will be experienced in the ASALs areas of sub-Saharan Africa (Niang *et al*., 2014). Observed seasonal rainfall trends In East Africa has exhibited variability and inconsistency with the projected trends (Hoscilo *et al*.,2014). Additionally, Shongwe *et al*. (2011) predicted increased mean rainfall of more than ~10% in the ASALs of Northern region of Kenya and a general wetter climate for East Africa. On the contrary, Omondi *et al*. (2014), reported declining trends in rainfall over the great horn of Africa (GHA).

Several authors have indicated that rainfall in East Africa has shown significant downward trends especially in the rainfall totals for the MAM season (Lyon and De Witt, 2012; Liebmann *et al*., 2014). Additionally, variations in spatial rainfall trends with insignificant variability in the MAM season have also been reported in some regions of Kenya and Uganda (Wandiga *et al*., 2010), nonetheless, models revealed contradictory seasonal trends. McSweeney *et al.* (2009), reported that since 1960s, rainfall observations for Kenya do not show statistically significant trends which shows inconsistency to a report by Funk *et al*. (2010) which pointed out that significant trends in rainfall were evident from a climatic trend analysis conducted for Kenya through monitoring and mapping trends for rainfall and temperature over the last 50 years (1960-2009) and extending the observed changes to up to 2025. The analysis showed that Kenya will have experienced a decrease in long-season rainfall by 2025 by more than a 100 millimeter (mm).

GCM projections for mean annual rainfall show consistent findings which indicate increase in annual rainfall in Kenya with projections showing increase in total rainfall to be largest during OND season (McSweeney *et al*., 2009). The models have constantly projected increase of the in the proportion of annual rainfall that falls in heavy events; the projected increase ranges from 1 to 13% in annual rainfall by the year 2090. An increase of more than ~ 15% in mean rainfall during MAM season by the mid-21st Century has also been projected (Shongwe *et al*., 2011). Similarly, a predictable increase in seasonal rainfall for OND rains has also been reported (Kirtman *et al*., 2013).

2.3 Farmer's Perception to Climate variability and change

Perception is the "process by which individuals are able to obtain information or stimuli from the environment and transform it into psychological awareness" (Ban and Hawkins, 2000). It is assumed that for households to decide whether to make an adjustment to any change or not, they must first perceive the change. It is thus vital to analyze perception and adaptation strategies of farming households because it helps to provide enhanced location specific insights and also generates information useful for guiding sustainable interventions towards addressing sustainable development challenges (Legesse *et al.*, 2012).

Research conducted Fraser *et al*. (2011) illustrated that communities living in the Kenyan ASALs are mainly dominated by smallholder farmers and pastoralists who depend on climate sensitive livelihoods which intensifies their vulnerability to climate change impacts. The author thus reiterates thus to guide the ASAL communities towards effective adaptation planning calls for an understanding of their perception to climate parameters and relating the perception with recorded climate data (Deressal *et al*., 2009; Silvestri *et al*., 2012). Additionally, Gichangi *et al.* (2015), states that in order to develop and have informed policies for successful adaptation process, it is necessary to understand farmer's perceptions and how they have their adapted to the experienced changes in their farming systems.

Research that was conducted by Rao *et al.* (2011) in Eastern part of Kenya showed that most of the smallholder farmers in the locality were mindful of the general local climate, its inconsistency and possible consequences it poses on their crop production. However, the study established that most of the farmers did not bring together the knowledge gained from the observations to differentiate long-term trends. This is because the theoretic distribution of seasonal conditions is more subjective mainly due to interactions between climate and other factors that influence crop production including but not limited to soil health, soil-water balance and land use change. Other studies have reported that farmers' perceptions may be different in several regions of a country and may also vary based on gender disparities, farming approaches as well as source of livelihoods (Thomas *et al*., 2007; Codjoe *et al*., 2012).

2.4 Food Security Dimensions and Climate Change

Effective food system significantly contributes to all dimensions of food security which are food availability, food accessibility, food utilization and stability. 'Food availability' refers to the existence of food within a population and is closely linked to efficacy of food production (FAO, 2009). Availability is greatly influenced by resources available such as irrigation, such as irrigation water or status of land fertility (FAO, 2009; Masila, 2015). 'Food Access' has been defined as when "individuals have sufficient incomes or other resources to purchase or trade to acquire levels of appropriate foods needed to sustain consumption of an adequate diet/nutrition level (FAO, 2009). Many aspects influence food accessibility, such as physical, social and policy related factors. Some of these aspects include; household proximity to suppliers and infrastructure and pricing (FAO, 2015). 'Food utilization' refers to ability to access food of good quality. It is vital that food is of nutritive value and healthy enough to provide the daily energy requirements of the consumers. Additionally, individuals should be in possession of the needed information and tools to make good use of the food available to them. Some of these components include availability of utilities to properly select, prepare, and store available and accessible foods. Lastly, 'food stability' implies that food availability, accessibility, and utilization dose not fluctuate but is relatively stable over time (FAO, 2009). Some of the threats to food stability include but not limited to: climate change, natural disasters, economic factors such as unsteady price fluctuations and conflicts. It is thus crucial to minimize any threats to food stability.

Despite the fact that food security is dependent on the four food security dimensions and not production alone, it critical for generation of new agricultural approaches that can feed the world's population both proficiently and equitably (Steiner 2011). There is quite a close link between agricultural productivity and food and nutrition security hence increased food production makes local food to be available (Pinstrup, 2013). The author further states that enhanced on-farm production increases food access thus enhancing household food security. Another significant aspect to reduced malnutrition is the nutritional value of the food produced mainly for households who source do own food production. The most persuasive force for decreasing malnutrition, predominantly in SSA, is enhancing availability of food through improved agricultural productivity as well as trade (Herrero *et al*., 2010; FAO, 2012). Increased trade translate to higher food prices which lessen demand for food since affordability of almost all agricultural commodities falloff under climate change (Herrero *et al*., 2010).

The resultant effects of climate change on agriculture sector either directly or indirectly impact on crop production and productivity. The resultant shocks are felt on the financial systems, and variation of prices, which consecutively distress food demand, hence impacting on calorie availability, and, ultimately, human welfare (Herrero *et al*., 2010; Tilman *et al*., 2011). Increase in commodity prices lead to lower food accessibility which is likely to lead to increases in malnutrition, especially of young children. It has been stated that climate change will likely escalate the number of malnourished children in 2025-2050 (FAO, 2012). Otherwise without climate change, child malnutrition levels are predicted to drop from 19%, 15% and 11% by 2000, 2025 and 2050 respectively. It is likely that due to impacts of climate change, there will be an upsurge in child malnutrition levels under all alternative climate change scenarios. The resultant effects will perhaps be intensified in high vulnerability areas, particularly the ASALs, mainly in SSA (Herrero *et al*., 2010). To support links between agriculture and biodiversity, there is need to incorporate a multi-functional base that combines biodiversity conservation, crop production in an effort to sustainably achieve food security (Sunderland *et al*., 2013).

In addition, there is need to adapt to and mitigate climate change while increasing productivity, food security, nutrition and sustainable livelihoods while taking into account diversity and traditional knowledge systems (UN, 2014). For this to happen, there is need to integrate scientific knowledge with research and development through a systems approach. This basis provides an opportunity for research processes to interrogate which sustainable production approaches can support sustainable crop production. Based on this context, this study conceptualized to integrate farmers' and other stakeholders into the research process towards investigating which CSA approaches had potential to improve food availability while minimizing threats posed to food stability by the changes in climate in Yatta (Sunderland *et al*., 2013).

2.5 Food Production under Changing Climate

In many parts of the ASALs of the World, extreme climatic events as well as average value of climate variables (rainfall, T_{max} and T_{min}) have a great influence on crop yields under rainfed agriculture (Adamgbe and Usoh, 2013). IPCC fifth assessment report (AR5), indicates that agricultural systems particularly in the semi-arid areas are experiencing increased vulnerability due to interface of climate change factors with non-climate drivers and stressors (IPCC, 2014a). Additionally, the report reiterates that climate change without proper adaptation is anticipated to impact in a negative way all aspects of food security including production, utilization, accessibility and price stability. The report further states that "in the recent past, continuing modifications in climate and extreme weather events have led to pronounced effects in food production systems which has undermined progress towards poverty alleviation and curbing food insecurity, while also negatively affecting on overall development efforts". Climate change impacts have largely affected either directly or indirectly economic sectors that largely depend on weather parameters and most notably agriculture and fisheries. The impact is also a threat to incomes and utilization patterns of communities whose livelihoods are dependent on these sectors (Foresight, 2011; IPCC, 2012).

According to Cooper *et al.* (2008), agricultural production in the semi-arid tropics (SAT) of Africa are increasingly experiencing intense repercussion which are mainly arising from variability in climate. The impacts are particularly being felt by smallholder farmers who mainly depend on subsistence and rain-fed agriculture for their living (FAO, 2013). Cooper *et al*. (2008) further reiterates that entire dependence on rain-fed agriculture coupled with deprived soil health and inadequate expertise has greatly led to increase in vulnerability of smallholder farmers to food insecurity. In Kenya, particularly, impacts arising from changes and variability in climate have had major effects on agricultural production with a decline and increased variability in crop production in certain areas which calls for transformational changes in the production patterns (Kalungu, 2013). These effects are mostly impacting on smallholder farmers, who are considered as the main producers of domestic food and rely mostly on subsistence agriculture and have limited capability to coping with the adverse changes in weather (FAO, 2012). Research has demonstrated that most of the staple crop production in Kenya is done under rainfed agriculture (Ekpoh, 2010; Herrero *et al*., 2010). With continued inconsistent rainfall patterns in most of the ASALs in Kenya, many households have suffered food shortages during drought and famine and only rely on food aid which creates a negative impact of dependence syndrome among farmers (GoK, 2009). A report by GoK (2010) highlighted that an approximation of over 10 million people suffered from chronic food insecurity and poor nutrition while 1-2 Million relied on emergency food assistance annually.

Maize (*Zea mays*) is considered as one of the most important food crop in sub-Saharan Africa where it's mostly grown under rainfed agriculture. The crop ranks top as important staple food crop for 96% of the Kenyan population with 125Kg per capita consumption while providing 40% of calorie requirements (Jones & Thornton, 2003). According to Parry *et al*. (1988), majority of the poor, vulnerable and undernourished rural households, in ASALs of lower eastern Kenya, depend on cereals, with maize as a prime source of their diet and nutrition. In most of the farming households in these areas, maize is highly valued because it produces better yields when grown under similar conditions which other crops which somehow tend to fail and provides large quantities of dietary energy. Additionally, the cereal is easily processed and cooked, is readily digestible cheaper compared to other cereals (Omoyo *et al*., 2015). However, recent research indicates that maize production has been characterized with occasional crop failure due to increasing patterns of unpredictable rains, severe droughts and high incidences of pests (Fisher *et al*., 2015).

Within the past ten years, maize has faced numerous threats due to outbreak of new pests in Kenya. These pests include the Maize lethal necrosis (MLN) disease which was first reported to occur in the Longisa division of Bomet County, Southern Rift Valley, Kenya in September 2011 (Wangai *et al*., 2012). It was reported that the disease caused yield losses of up to 90% with an estimated grain loss of 126,000 metric tons valued at $52 million in Kenya in the year 2012 (Mahuku *et al*., 2015). Another pest which has become a threat to maize production is the Fall Armyworm (*Spodoptera frugiperda*) (FAW). The pest is reported to be native to tropical and sub-tropical America and has over time spread and become a serious pest of maize and other crops in many parts of the World. The pest has been reported to have invaded Africa in the recent past with its first detections reported in Central and Western Africa in early 2016. The pest was first reported in Kenya in May, 2017 and has been reported to cause huge damage to maize crop which has been estimated to 25-67% for maize in many countries (Mahuku *et al*., 2015).

It is estimated that occasional drought stress is faced in approximately 40% of Africa's maize growing area with yield losses of ten to twenty five percent (10-25%) having been experienced. Reports by CIMMYT (2014) show that almost 25% of the maize crop is affected by frequent droughts resulting to losses of up to half of the harvest. A study by Omoyo *et al*. (2015), showed that under rainfed conditions maize yield and generally food security was significantly influenced by the onset, cessation, distribution and amount of rainfall conducted in the lower Eastern region of Kenya. Additionally, the study revealed that there was a drastic reduction of maize yields of up to 15kg per year in Machakos, Kitui and Makueni Counties which was mainly due to inconsistency and variation in climate parameters. The results further showed that variations in climate variables (rainfall, temperature and evaporation) had an extreme effect on maize yield in lower eastern region of Kenya over the period 1979-2009. This implies that maize production within the ASALs where it's mostly grown under rainfed agriculture; reduction in rainfall amounts, increase in temperatures and high evapotranspiration will ultimately affect the crop yield (Omoyo *et al*., 2015).

Green gram (*Vigna radiata* L.), or mung bean which is locally known as Pojo (Swahili) or Ndengu in Kenya, is an important annual legume crop which is grown for its seed and its benefit of nitrogen (N) fixation through nodule symbiosis with rhizobia (Swaminathan *et al*., 2012). The crop is native to India where it was naturalized as early as 1500BC (Zhang *et al*., 2008) but later on cultivated Green-gram was established in Africa, southern Europe, United States, eastern Asia and West Indies. It is currently widespread across the tropics (Oplinger, 1990; Swaminathan *et al*., 2012). In the warm and dry parts of Eastern Kenya, the crop has been adopted as a significant subsistence and cash crop as well as for its use as hay, green manure and cover crop (Shakoor *et al*., 1984).

The seed when cooked provides 25% protein content and can thus be consumed as a source of protein in the absence of meat (DPP, 2010; SASOL, 2015). The plant is hardy and early maturing with ability to tolerate drought and can tolerate shade which make it an important crop for intercropping with cereals such as maize (*Z. mays* L.) or sorghum (*Sorghum angustum* L.) (Waite *et al*., 1984; Zhang *et al*., 2008).

Green gram performs well at an altitude of 0-1600m with rainfall requirement of 350-700mm per annum, with 650mm of rainfall as the optimum above sea level and under warm climatic conditions (28°C to 30°C) (Morton *et al.*, 1982; Mogosti, 2006; DPP, 2010; SASOL, 2015). Since green gram is a drought tolerant crop, too much rainfall and cool temperatures lead to accelerated vegetative development with a reduction in pod setting and enlargement (Mutua *et al*., 1990; SASOL, 2015). The plant grows well in red sandy loam soils at pH range of 5.5-7.5 but performs poorly on heavy clay soils due to poor drainage and is somewhat tolerant of saline soils (Oplinger *et al*., 1990). However limited information is available on green gram production and yielding in Kenya (Woomer *et al*., 1997). In the recent past, the crop has gained a lot of popularity in Kenya and several interventions are on course to promote its production in the ASAL regions in a geared effort to build farmers' resilience to the impacts of increasingly frequent droughts. The Kenyan government, private sector and NGOs are increasingly supporting farmers in ASALs regions of the country to grow drought tolerant crops 'dryland crops' which can withstand harsh weather conditions (ASDSP, 2016).

The County Government of Kitui has shown a lot of interest in Green gram and has been promoting its production to farmers as one of the most suitable and profitable legumes for the County. Sahelian Solution Foundation (SASOL), a local Non-Governmental Organization (NGO), has been encouraging Green gram farming within the framework of enhancing food security with the Kenya Dryland Farming Project (KDFP). During the year 2014, this project had a target to reach 1500 farmers in Kitui Rural and Kitui South sub counties (SASOL, 2015). Farm Africa has also been working with farming households in the Mwingi and Kitui districts to better their incomes by cultivating drought-tolerant, commercially-attractive sorghum and Green-gram crops (Farm Africa, 2016).

2.6 Climate Change Adaptation and Resilience

According to IPCC (2007a), adaptation to climate change refers to "making adjustments in the natural or human structures as a means of responding to valid or expected climatic stimuli or their consequences, which helps to restrain harm or make the most of valuable opportunities". According to IPCC (2007b) report, despite the efforts to avert climate variability through adaptation in some regions, this may not be sufficient to alleviate expected adjustments in climate. Some of the identified key adaptation priority areas which when sustained could bring sustainable development are "sustainable forest management, land and water; disaster risk reduction; watershed management; coastal and urban development; improved agricultural productivity, health and social issues" (IAASTD 2008a, IAASTD 2008b; World Bank, 2009). According to FAO (2009), effective farmers' adaptation calls for an integrated approach which includes agro-ecosystems (crops, livestock, forests, woodlands and waters).

In his findings, Morton (2007) stated that smallholder and subsistence farmers' adaptation options are mostly based on local setting although some of the most vital resilience factors that could enable communities cope with climate change impacts include domestic labour, existing patterns of diversification and indigenous knowledge. Walker (2007) supports that adoption of approaches that integrate farmers through participatory learning in the very beginning of selecting and implementation of adaption technologies through use of indigenous knowledge, have proven to be successful in improving agricultural yields. The IPCC fifth assessment report (AR5) highlights five common principles for building effective adaptation as well as adaptive capacity. One of the key principles is "to combine 'soft path' options and flexible and iterative knowledge with scientific and infrastructural approaches and joining together modern, local and indigenous knowledge when developing adaptation strategies" (IPCC, 2014a). The report suggests that these forms of knowledge should be integrated with existing practices in order to increase effectiveness of adaptation.

Several studies have indicated that the poorest and special groups of people in the society are more exposed to impacts posed by change in climate due to their inadequate capacity to respond to, recover from or adapt to climate-related shocks and stresses (FAO, WFP and IFAD, 2012; Steele *et al*., 2015). It is thus critical to enhance the ability of the poor and vulnerable in rural communities and associated stakeholders to enhance their coping capacity to constraints and opportunities associated with climatic changes (Cooper *et al*., 2008). Dixon and Stringer (2015), state that there is an increasing interest to strengthen climate change resilience of smallholder farmers although it is not clear which tools and framework already exists that focus on climate resilience and the extent to which they reflect current resilience thinking.

Adaptation to climate change strategies can incorporate a series of strategies which could be incremental and others transformational (Brooks *et al*., 2011; Kates *et al*., 2012). "Transformative adaptation" calls for farmers to make a major change in their farming systems like shifting from one farming system to another. For instance, farmers need to adopt crop varieties which have the ability to survive in harsh weather conditions and emerging pests and diseases. In addition, water harvesting should be done when it's raining so that it can be used when it gets dry with this element becoming increasingly important in sub-Saharan Africa (Pye-Smith, 2018). Campbell *et al*. (2014), states that to effectively build farmers' adaptive capacity there is need to enhance agricultural ecosystems that would support enhanced resilience. This can be achieved through effective management of crop growth support systems which include: soil, water and plant nutrient as well as better water storage (on-farm and irrigation), access to and adoption of crop varieties that can resist drought/heat, spread of farm enterprises, knowledge dissemination and local adaptation planning among others.

Some studies have assessed factors that influence farmers' adaptation strategies to climatic changes. For example, Maddison (2006) and Hassan and Nhemachena (2008); reported that different socio-economic factors like farmers' experience, education, accessibility to market and availability to information via extension services greatly influence the choice of adaptation options that farmers adopt. Hassan and Nhemachena (2008) further asserts that some factors that could enhance adaptation for most farmers in Africa include availability of extension agents services, market accessibility, new technologies, and credit services among other. On the other hand, (Smit and Wandel, 2006) point out that factors that influence farmers' capacity to undertake adaptation may include: financial access, managerial ability, technological and information resources, infrastructure and institutional environment. Although Vincent (2007) stated that farmers' choice of adaptation depends on their local context, he acknowledged that the main factors that shape the adaptive capacity of a country included among others their demographic structure, universal interconnectivity, financial strength and wellbeing, institutional stability and wellbeing, and natural resource dependence. According to Bryan *et al*. (2013), although many households have been able to make small adjustments to their farming practices (like making changes in planting choice), only limited number of households have the potential to make more expensive and involving investments (like agroforestry or irrigation) in their farms, despite the fact that they aspire to put in place such measures.

In the context of climate change, 'resilience' "consists of three capacity which ascertain how and the extent to which social and institutional systems can deal with and adapt to climate change impacts while at the same time retain their basic structure and functions" (FAO, 2016). The three capacities include: 'adaptive capacity' which consists of coping or survival strategy, risk management and saving groups; 'absorptive capacity' which entails use of assets, attitudes/motivation, livelihood diversification and human capital and 'transformative capacity' which integrates policies/regulations, governance mechanisms, infrastructure, community networks and formal safety nets. According to a report by FAO (2016), "to bring an end to global poverty and hunger calls for enhanced resilience in farming systems through introduction of sustainable practices which can sustainably increase food security". The report further states that 'for nations to effectively achieve eradication of global poverty and hunger, they need to enhance the resilience of smallholder farmers' through adoption of sustainable approaches for land production, water management, fisheries and forestry management practices. According to D' Silva *et al*. (2010), adoption of sustainable farming practices such as minimum tillage, use of improved crop varieties (such as nitrogen efficient, heat/drought tolerant) and integrated soil fertility management extends benefits to farming communities especially in the long run. However, for these benefits to be accrued, it is indeed a critical responsibility for the farming communities to accept and implement them in their farming systems. However, despite their potential, adoption of these practices is still very limited due to improper government policies; such as limited subsidies to farm input which has led to continuous use of unsustainable production practices.

2.7 Climate-Smart Agriculture

To build sustainable agriculture with the ability to adapt to impacts posed by changes in climate, there is an increasing focus on promotion and adoption of CSA practices which have potential of triple CSA benefits. There is already some evidence that adoption of CSA practices can arrest the perpetuation of climate change through reduction of emissions of GHGs such as nitrous oxide (from applied fertilizers). CSA has continued to increase in popularity as a means of getting existing technologies off the shelf and getting them to the reach of farmers (FAO, 2013). Examples of some CSA practices which can be potentially relevant to Kenya's agricultural context include: CA; rain-water harvesting; planting more resilient crop varieties (drought or flood-resistance); crop rotations; agro-forestry; intercropping with nitrogen-fixing legumes and cover crops; crop fertilization with livestock and organic manure among others (Bryan *et al.*, 2013). Four wide classes of CSA practices which could suit smallholder farmers in SSA, by the virtue of their simplicity to be used and realize the ultimate potential of the three core principles of CSA have been identified (McCarthy and Brubaker, 2014). The four broad categories of CSA are: CA, agroforestry, soil and water conservation (SWC) and irrigation and drainage. This study considered two CSA categories from the four which are conservation agriculture and SWC. These have been discussed in detail as outlined in sections below.

2.6.1 Conservation agriculture

CA is "a farming approach which has a potential to manage agro-ecosystems in a sustainable manner for better and persistent crop productivity, increased profits and food security while sustainably conserving the natural resource base and the environment" (FAO, 2011). The approach achieves 'resource-efficient' crop production based on its three core principles: the first principle is use of minimum soil tillage or zero tillage during land preparation which involves altering ploughing methods in order to minimize soil disturbance; the second principle is ensuring continuous soil cover with organic matter which could be in the form of crop residues, cover crops and trees which helps to reduce soil erosion and the third principle is diversified crop rotations while considering use legumes which are able to fix nitrogen such as beans as well as trees which have the potential to add soil fertility as well as improve soil structure. The principle of minimum soil disturbance, seeks to minimize or totally avoid mechanical tilling thus helping to sustain soil porosity while allowing water to infiltrate through the soil in order to reach crop roots and slow down erosion processes (Kaczan *et al*., 2013). However, use of synthetic chemicals is not eliminated entirely from the CA models but it decreases gradually, for instance; weed management in the initial stages is usually achieved through increased use of herbicides and also entails use of pesticides for pest management. It is thus imperative to state that one of the benefits of CA is usually the long-term reduction in input requirements (Kaczan *et al*., 2013). CA also makes use of crop residue left on the field after crop harvesting which entirely supports improvement of soil moisture retention and nutrient uptake (Bernier *et al*., 2015).

CA has gained its popularity over the years with reports indicating that in the year 2011, the total area of its adoption Worldwide was estimated at 125 Million ha, or 9 percent of arable cropped land (Kassam *et al*., 2012). It was estimated that around 69 percent of arable land in Australia and New Zealand and 57.5 percent in South America was cultivated under CA (Friedrich *et al*., 2012). In contrast, only 368,000 ha of crop land in Africa is cultivated using CA, which is approximately 0.1 percent of the continent's arable cropland and represents only 0.3 percent of the CA area globally. The limited acreage of arable land under CA in SSA shows that the practice has experienced limited adoption among smallholder farmers with major constraints identified as competing use for crop residues, increased demand for domestic labor especially for weeding and limited access to external inputs (Giller *et al*., 2009). However, adoption of CA in Zambia has shown to be relatively substantial with Friedrich *et al*. (2012) reporting that CA cultivation was being practiced in approximately 40,000 ha, which is a greater acreage than in any other SSA country. The significant adoption of CA in Zambia has been attributed to the wide and active promotion of CA by the NGOs, farmer organizations, research institutions and the FAO (Knowler and Bradshaw, 2007; FAO, 2011).

The next sections provide an overview of status of CA in Kenya and an overview of demonstrated impact of CA on crop yield.

2.6.2 Conservation Agriculture and its adoption in Kenya

The first CA project in Kenya was launched in the year 2002/2003 and was supported by the German Government (Under German Trust Fund) and was coordinated by the Africa Conservation Tillage (ACT) Network and the FAO. A follow-up phase was done through a project called

Conservation Agriculture for Sustainable Agriculture and Rural Department (CA-SARD) which started during short rains in the year 2004 and lasted for two years. By the end of the project, farmers had successfully experimented with CA practices for one to four seasons. Through the project advancement of CA interventions was evident and enormous progress was made particularly by adopting farmer field schools (FFS) methods, training support staff and farmers, bringing in advanced CA equipment, advancing artisan training and forging links with private sector (Kaumbutho and Kienzle, 2007). A second phase of CA-SARD was initiated in March 2007 and lasted up to 2010 and was building on lessons and recommendations made in the first phase. Evidence of CA adoption is said to be visible in areas where CA-SARD, ICRAF, SCC-Vi, Millennium Development and KARI projects have had impact. The areas include Large Nzoia River Basin covering Kitale, Bungoma, Vihiga, Bunyore, Limuru, Laikipia district etc. In all these areas nitrogen fixing agroforestry crops, legumes and trees are mixed with the main crops particularly bananas and maize. In most of the ASALs where marginal rains are experienced such as Machakos, Makueni and Kitui Counties in Eastern region of Kenya, one of the sustainable land management practices that farmers use to conserve water is use of shallow planting furrows and mulch. Some farmers have also adopted planting of cover crops such as Dolichos lablab and pigeon pea which help to prevent evaporation during dry seasons mostly after short rains (MAM). Some large scale farmers in Laikipia have adopted and have been practicing CA for over three decades but smallholder farmers are still learning on the system from various donor-funded projects (Kaumbutho and Kienzle, 2007).

2.6.3 Conservation Agriculture and Crop yield

Reports on experimental trials (mainly from North America, Australia and Europe) showed that there was a slight increase in crop yields in the CA plots (that increases over time) compared to conventional tillage especially in dry conditions (Farooq *et al*., 2011). Success in the use of CA has also been demonstrated in Malawi where the practice has been tried for almost 10 years by Total Land Care and International Maize and Wheat Improvement Centre (CIMMYT). CA trials on farmers' fields showed its capacity to produce superior and steadier yields compared to the conventional ridge tillage system. Results obtained indicated that from the subsequent cropping season onwards, maize yields were 11-70% higher with use of CA, especially in years which recorded little rainfall (Nyasimi *et al*., 2014). In another research which was conducted in Malawi by Ngwira *et al*. (2012), showed that there were positive benefits on maize yields grown under CA after the first season of experimentation with the highest increases of 2.7Mgha^{-1} and 2.3Mgha^{-1} additional yield in CA plots planted with monocrop maize and CA maize-legume intercrop respectively as compared to the traditional tillage. Additionally, the practice has been evaluated in Zambia by the Conservation Farming Unit which has been working with smallholders since the mid-1990s. By the end of 2010, over 180,000 farmers were reported to be practicing CA, and majority farmers reported double yield for their maize crop (Nkhoma *et al*., 2017). Results obtained from a wheat and barley farmer in Laikipia District of Kenya showed that crop yield increased with adoption of CA with better returns realized in the second cropping season as there was significant buildup of soil cover from crop residues (Kaumbutho and Kienzle, 2007).

2.6.4 Soil and Water Conservation

Better and efficient water management is one of the most effective adaptation approaches since it helps in making more water available to crops which is crucial for increasing agricultural production (Rockstrom and Barron, 2010). Adoption of rain water harvesting has been cited as key to achieving food security in the ASALs areas (Masila *et al*., 2015). During the Climate Change Convention held in Nairobi-Kenya in 2006 rain water harvesting was recognized as an alternative option that can address current water demand and also provide water security against future droughts especially in African countries (Mashood *et al*., 2011). Although the Kenyan ministry of agriculture and other stakeholders including non-governmental organizations (NGOs) have been sensitizing and training smallholder farmers on various on-farm rainwater harvesting and conservation techniques, their adoption has still remained very low hence continued levels of food insecurity in the country (Masila *et al*., 2015). Bouwer (2000) also points out that water storage is needed to protect water resources against changes in climatic conditions. This includes, storing water during times of water surplus and use it during water shortage.

Climate change effects have compounded constraints in water availability mainly due to increase in temperature which causes loss of water through evaporation, increased frequency of droughts as well as erratic rains. These effects are likely to have significant implications on water resources at farm level thus affecting agricultural productivity and increasing farmers' susceptibility to climate change. It is thus imperative to have sustainable water management strategies that will guarantee water availability for sustainable crop production. According to Ngigi (2009), "adaptive water management strategies refer to interventions aimed at improving water availability and utilization for agricultural production to reduce climate change risks. This would ensure both the current and future water needs are met as well help in achieving economic growth in SSA". The author further states that adaptive water management strategy is one of the main adaptation measures that can be practiced by farmers. Such water management strategies include water storage, harvesting of rainwater, sustainable groundwater use, soil and water conservation, conservation agriculture (CA), and increased water use efficiency (Ngigi, 2009). According to Mashood *et al*. (2011), adaptive management of water involves better management of rainwater and soil moisture, as well as investment in small irrigation technologies and supplementary irrigation which can improve agricultural productivity and hence reduce poverty.

2.6.5 Use of Zai pits

'Zai' is a conventional water and soil conservation method that has its origin in Mali in the Dogon area. "It's one of the most important water conservation techniques that has been implemented in Sahelian countries since 1980s and has developed land improvement practices on a wide scale in Burkina Faso and Niger" (Danjuma and Mohammed, 2015). The technique was rediscovered after the enormous drought which occurred in 1973/74 and was later improved by development partners while integrating farmers (Abdo, 2014; Danjuma and Mohammed, 2015). Use of Zai originated in the Western Sahel where farmers are faced with continuous challenge of producing adequate food due to soils which are encrusted and infertile and the fact that the area receives low and often highly variable rains (Motis, D"Aiuto, and Lingbeek, 2013).

Zaipits make use of a grid of dug holes where manure is incorporated to improve soil fertility. According to different authors, Zaipits measurements could be varied; according to Danjuma, *et al*. (2015), Zaipits consist holes which area dug out in grids and have a diameter of 15-20 cm by a depth of 10-15 cm or more, with a spacing of 70-80 cm apart, which amount to around 10 000 pits per ha while Kaluli *et al*. (2012), states that "Zai are usually excavated with a diameter of 0.3-0.6 m and 0.3 m deep". The holes harvest rain water at farm level and have the potential to boost soil water holding capacity by up to 5 times while collecting up to 25% of the runoff in the immediate area surrounding the hole (Kaluli *et al*., 2012). The technique has proven as one of the useful approaches to support farmers' adaptation in the ASALs through several ways: reduction of runoff and soil erosion as well as reduced risks associated with erratic and declining rainfall, has ability to store rainfall water for longer periods which provides a cushion against mid-season dry spells and it enhances water and nutrients use efficiency thus increasing crop productivity (Danjuma *et al.*, 2015).

2.8 Research Gaps Identified

A significant body of literature addresses climate change impacts on most critical sectors of economy including agriculture, fisheries, livestock, forestry and tourism. Most studies have shown that implementation of sustainable adaptation measures serves as a sure way of overcoming adverse impacts posed by variability and changes and variability in climate (Mburu *et al.*, 2015; Recha *et al.*, 2016; Gichangi and Gatheru (2018)). According to Cooper *et al.* (2008), although households have made some efforts to adapt to changes experienced from recurrent drought using some of the coping strategies like diversification into off-farm activities, this may not be a feasible option for many smallholder farmers who are dependent on rainfed agriculture. There is thus the need to enhance adoption of farming options and innovations that can enhance smallholder farmers' resilience.

Several studies have documented that knowledge of farmers' perception of CC deepens an understanding of the realities of climate change at the local level which is critical for effective adaptation as well as policy formulation and implementation (Gichangi *et al.*, 2015; Ayanlade *et al.*, 2017; Mutandwa *et al.*, 2019). On contrary, most policies on adaptation are formulated at the national level without taking cognizant of farmers' indigenous knowledge and what solutions are already available in the local context. This study was conducted in view that several studies have been conducted to investigate historical climate trends in Kenya (Gichangi *et al.*, 2015, Recha *et al.*, 2016; Bobadoye *at al*., 2014), review climate change impacts as well as analyze smallholder farmers' perceptions and adaptation to CC (Mutunga *et al*., 2017; Evelyn *et al*., 2017; Chepkoech *et al*., 2018). The study however considered that limited research has attempted to document smallholder farmers' perceptions of climate variability and change and linking the perception to historical climate trends in Kenya (Bobadoye *et al*., 2016; Nuamah and Botchway, 2019; Chepkoech *et al*., 2019).

This study took into account that although, several studies have shown that farmers had adapted to climate change by embracing and implementing changes in their farms based on their experiences and perception of CC in their local setting such information was limited. Further analysis showed that some of the farmers have continually embraced some of the adaptation practices that have been under promotion such as water harvesting (Mburu *et al*., 2015; Recha *et al*., 2016; Agesa *et al*., 2019), changing cropping regimes (Bryan *et al*., 2013; Chivenge *et al*., 2015) and use of soil-water management strategies (Recha *et al*., 2016). According to Pye-Smith (2018), although there is enough evidence to suggest that practices such as agro-forestry and CA can increase crop yields and incomes, sequester carbon and help farmers to better adapt to changing climate, quantitative data is limited. Although a significant success on benefits of minimum tillage in increasing crop yield has been reported in semi-arid sub-Saharan Africa, documented success with quantitative evidence is limited and scattered (Branca *et al*., 2011; Nyasimi *et al*., 2014; Nkhoma *et al*., 2017). To upscale and promote adoption of the CSA options requires critical baseline information which is not yet available. Such information includes location-specific data on which adaptation practices have proven to work better and their rate of adoption. Lack of this information is thus a hindrance to the execution of appropriate policy responses, climate risk management and upscaling adoption of sustainable adaptation options. This study thus provided a rationale for evaluating which on-farm adaptation strategies have been implemented in Yatta, their rate of adoption and the extent to which they had enhanced farmers' ability to cope with climate change impacts. The study also considered the need to implement research which can help establish which CSA practices work best and can be successfully adopted by farmers, the barriers to adoption and lessons which can help in up-scaling and spread of successful practices.

Finally the study considered that in most of the case studies which have shown evidence of farmers' adaptation to the changing climate, involvement of universities and learning institutions in knowledge and technology transfer on CSA is missing. In addition, collaboration from multi-stakeholders and active community participation which is significant for successful implementation of CSA is not evident in most cases. Reviewed literature also indicate that uptake of CSA practices has also been compromised by limited farmers' knowledge on promising initiatives combined with insufficient, inconsistent and conflicting advice by extension officers. This study thus was thus guided by this gap by and thus incorporated farmers into the research process through employing a participatory action learning approach and effectively building farmers’ capacity at all levels (Nyasimi *et al*., 2014).

CHAPTER THREE: DATA AND METHODOLOGY

3.1 Introduction

This chapter gives a detailed description and location of the area of study; it also describes the conceptual framework which illustrates the variables considered in the study. The chapter further describes methods used in the research while clearly specifying the procedures followed to achieve the study objectives. It broadly outlines the research design adopted, the study population, sampling methods and techniques, all the data that was used in the research, data sources and data collection procedures. It also gives an outline of tools used for data collection, processes conducted to assure quality of the research process (piloting of the research tools; training of enumerators; logistics and management planning), data verification, cleaning, analysis and presentation.

3.2 Description of the study area

3.2.1 Geographical location

Machakos County is amongst the Counties located in the Eastern part of Kenya (GOK, 2013). It borders a total of 8 Counties: Embu to the North, Kitui to the East, Makueni to the South, Kajiado to the South West, Muranga and Kirinyanga to the North West, Nairobi and Kiambu to the West (KNBS, 2015). The County stretches from latitudes 0^o 45’ South to 1^o 31’ South and longitudes 36^o 45’ East to 37^o 45’ East. It has an altitude of 1000-1600 meters above sea level. The County is divided into eight (8) administrative sub-Counties which are Machakos town, Masinga, Yatta, Kangundo, Matungulu, Kathiani, Mavoko and Mwala (Table 1). The field study was conducted in Yatta sub-County while focusing on selected villages (Figure 1). The sub-County was curved from the Machakos County in January 2007 and is divided into five administrative wards (Kithimani, Ikombe, Ndalani, Matuu and Katangi) (KNBS, 2015). The Yatta sub-County was purposively selected because of its vulnerability to drought and extreme climatic events (Machakos DEAP 2009-2013). A thorough literature review showed that there was little documentation of research findings on farming systems and impacts of climate variability and change in the area. The area is dominated by smallholder farmers whose livelihoods depend mostly on rainfed agriculture hence need to build their resilience to climate impacts. Additionally, the community is known to be cohesive, receptive to new ideas and has a wealthy of indigenous knowledge which was very useful in the study. Finally, the area is located along Thika-Garissa highway hence it was easily accessible by the researcher.

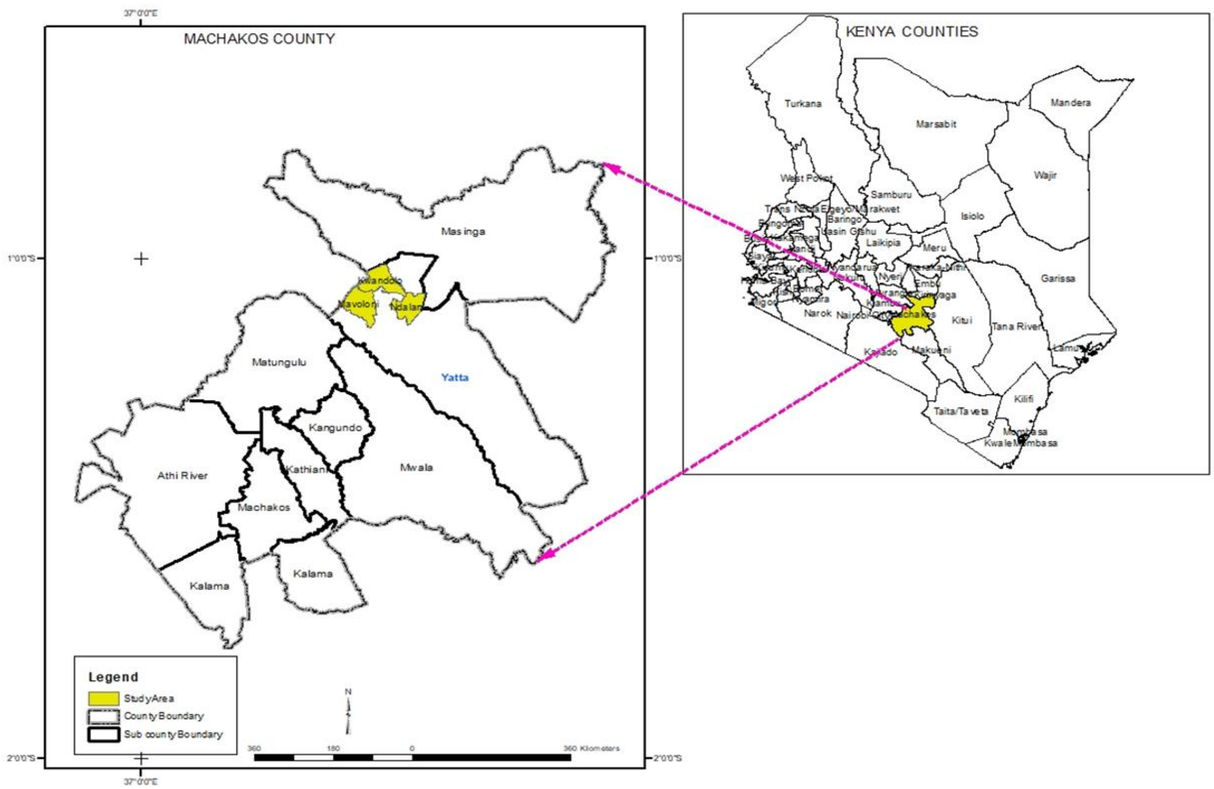


Figure 1: A map of the study area
Source: KNBS, 2015

Table 1: Machakos County administrative units by sub-County, 2014

Sub-County	No. of Divisions	No. of Locations	No. of Sub-locations
Machakos Town	2	13	39
Kangundo	3	9	25
Yatta	3	8	23
Matungulu	3	10	30
Kathiani	1	4	21
Mavoko	4	7	14
Masinga	2	9	29
Mwala	4	15	58
Total	22	75	239

Source: Ministry of Interior and Coordination of National Government, Machakos County (2014)

3.2.2 *Population and demographics*

Machakos County's population is 1,098,584 persons with male to female ratio of 49% and 51% respectively with a total of 264,500 households (KNBS, 2009). It covers an area of 6,208sq.km with a population density of 177persons per sq.km. The population density and distribution in the County is mainly determined by the economic activities carried out in the specific sub-counties. From the demographic data, it is apparent that Kangundo Sub-County has the highest population density followed by Kathiani. This could be attributed to the fact that Kangundo and Kathiani have good agricultural land with fertile soils and favorable climate. Masinga Sub-county is sparsely populated with a population density of 90 followed by Yatta sub-County which has a population of 147,579 people with a population density of 140 (KNBS, 2009). The Yatta comprises of five administrative wards (Ndalani, Kithimani, Ikombe, Matuu and Katangi) (shown in Table 2).

Table 2: Yatta sub-County administrative wards population

Ward	**Population (National Census, 2009)**	**Area (Sq. Km)**	**Description of sub-locations**
Kithimani	33,714	196.90	Kambi Ya Ndeke, Kithendu, Kithimani and Mamba
Ikombe	34,683	331.40	Kitheuni, Makutano, Mathingau, Kyasioni, Ikombe and Kinyaata
Ndalani	30,256	167.70	Ndalani, Kivingoni, Kisiiki, Mavoloni, Kwa Ndolo
Matuu	27,145	126.40	Katulani, Kaluluini, Matuu and Kakuumini
Katangi	21,781	234.90	Mekilingi, Kyua, Syokisinga and Katangi

Source: Kenya National Bureau of Statistics (2009)

Table 3: Population and Density Distribution by Constituency/Sub-County

Constituency	**Population**	**Density (km^2)**	**No. of Wards**
Machakos Town	199,211	215	7
Masinga	125,940	90	5
Yatta	147,579	140	5
Kangundo	94,367	533	4
Kathiani	104,217	503	4
Mavoko	139,502	165	4
Matungulu	124,736	216	5
Mwala	163,032	160	6
TOTAL	1,098,584	177	40

*Source**:** Kenya National Bureau of Statistics (2009)*

3.2.3 Natural and Biophysical Resources

The County is a host to several natural and biophysical resources. The County is home to major tourist sites. These include Ol Donyo Sabuk National Park, Fourteen Falls, Iveti hills, Lukenya hills, Yatta plateau, Kyamwilu gravitational defying area, Komarock shrine, Mcmillian Castle, wood carving in Wamunyu, Masaku Footprint Rock in Kiima Kimwe, Masinga dam, Maruba dam, Machakos People's Park and Kenyatta Stadium. Wildlife in the County include antelopes, zebras, wildbeasts, elands, giraffes, thomson's gazelles, grant gazelles, elephants, hippopotamus, buffaloes, waterbucks, lions, cheetahs, leopards, warthogs, ostriches, impalas, dik-diks, hyena, reedbucks and a variety of birds.

3.2.4 Climatic Conditions

The County is located in the ASALs of Kenya which are characterized by warm and dry climate for most parts of the year. The rainfall is low and unpredictable with a bimodal rainfall pattern which is distributed in two seasons; with short rains occurring in October, November and December (OND season) and long rains occurring in March, April and May (MAM season). The ASALs receive rainfall amounts less than 500mm but with marked spatial and temporal variations. The main production season is during the short rains with little production during the long rains. Temperature has been on the increase and ranges between 25-29^{o}C and this normally aggravates the inadequate rains leading to drying up of seasonal streams leading to insufficient water sources for both human & livestock use (GOK, 2013).

3.2.5 Water Resources

Water resources in the County are mainly seasonal rivers, dams and springs. The County has two perennial rivers; Athi River which traverses the County and Tana River which forms the County boundary with Embu and Tharaka Nithi counties. The dams include Maruba, which is the most important water source for Machakos town whereas Masinga dam on Tana River is shared between Machakos and Embu counties. In addition, several earth dams and springs across the County serve as water resources. Underground water sources (boreholes and wells) supplement surface water sources. Most of these water sources are under threat of pollution from agricultural chemicals, urban and industrial wastes especially Athi River, which is under threat of pollution from the

Nairobi city and adjacent towns. The Yatta Sub-County is served by two main rivers which have water throughout the year: Thika River which draws water from Aberdare Mountain and feeds the Yatta canal and Ianguni River which is fed by the Yatta canal. Besides there are also seasonal streams including Kauthulini, Kikwa and Kawituoo among others.

3.2.6 Land Uses and Resources

Machakos County occupies a total surface area of 6,208.2Km^2 with arable area, non-arable area and water mass occupying 3,720.2Km^2, 2,436.0Km^2 and 124.0Km^2 respectively. Soils in Yatta sub-County build up from undifferentiated basement system rocks thus are Acrisols, with Luvisols and Ferralsols. They are made of sandy clay to clay with topsoil of loamy sand to sandy loam which is well drained, moderately deep, dark red to dark reddish brown and friable to firm (Agumba, 1985). Some of these soils are generally low in fertility, highly erodible which implies that crop production in some areas can be a real challenge. Due to low agricultural productivity, locals in the community have resorted to charcoal burning and selling of firewood which has led to loss of trees leading to loss of carbon sinks. Most of the County residents use unsustainable cooking methods such as firewood and charcoal as the major source of fuel. This has resulted to deforestation in most areas leading to rampant and expansive soil erosion. There is also a lot of rampant and unsustainable sand harvesting from rivers and streams which has led to decreased water holding capacity of rivers and lowering the water table. This has caused drying and disappearance of rivers resulting to water scarcity for both domestic and commercial use.

3.2.7 Vulnerabilities

3.2.7.1 Biophysical vulnerabilities

Emissions from manufacturing factories have caused airborne related illnesses to part of population that live in these areas (GoK, 2018). Moreover, pollution of rivers through discharge of industrial wastes has negatively affected aquatic life and quality of agricultural yields produced through irrigation farming along the rivers. Deforestation has led to great reduction of tree cover which has negatively affected attraction of rain across the County. Due to the changing climate, the area has experienced some crop pest incidences which were never experienced 30 years ago for instance “Frost bite” which is related to sharp cold stress especially in the mornings has continuously affected crops like maize, beans and pigeon peas leading to decreased production.

Some crop pests like stem borer which was never a challenge twenty years ago has recently emerged and is significantly affecting maize production. Additionally, the Maize Lethal Necrosis Disease (MLND) and recently the Fall Armyworm have also become a menace to maize production. Whiteflies and aphids have also become a problem especially on greengrams and cowpeas.

3.2.7.2 Socio-economic vulnerabilities

The area has become very vulnerable due to dependence on rainfed agriculture for economic and social development. Food deficit has thus become a common phenomenon in the area due to unreliable rainfall patterns and recurrent droughts. Some households don't have sustainable sources of income which means that no money is available to buy food stuff leave alone to cater for other basic and social needs including school fees and medication. Economic constraints has resulted to low adoption of modern farming methods, school drop outs especially at high school level, deaths due to in access to medical care and some households still depend on food aid . Insufficient food and lack of sustainable livelihoods has resulted to dependence on climate-sensitive resources including cutting of trees for charcoal burning and firewood and sand harvesting as a means of livelihood which has in turn aggravated vulnerability trends.

3.2.8 Social-economic Setting

The main factors influencing population density in the area are mainly land productivity and water availability. Based on the fact that agriculture is the main economic activity, most of the population has settled around water sources and fertile lands. From the KNBS census data of 2009, female population was higher than the male population, and the old people constitute about 1/3 of the population. Poverty is prevalent in the area as demonstrated by failure of parents to educate their children at high school level, poorly maintained farms and some households have also been affected by HIV.

3.3 Conceptual Framework

Climate variability and change has had intense impacts especially in ASALs where majority of smallholder on rainfed agriculture. The conceptual framework presented below (Figure 2) shows the variables included in this study and their relationship. It describes the impacts posed by climate variability and change and pathway towards realizing sustainable food security (dependent variable) for smallholder farmers through integration of CSA (independent variable) into smallholder farmers' farming systems. Farmers' perception to any change(s) in climatic trends and the impact of the experienced change to their livelihoods is a key determinant towards making an informed choice to change or adjust their farming practice(s). Farmers' perceptions and their decision to adapt to the changing climate are thus considered as the moderating variables. Understanding farmers' perception and what adaptation strategies they have employed is thus critical towards designing sustainable farming approaches towards resilience and food security. This research considered integration of CA and Zaipits as CSA options in order to counter impacts posed by variability and changes in climate to crop production. To enhance sustainability and adoption of the CSA models the research adopted participatory action learning approach while incorporating new scientific knowledge into farmers' indigenous knowledge.

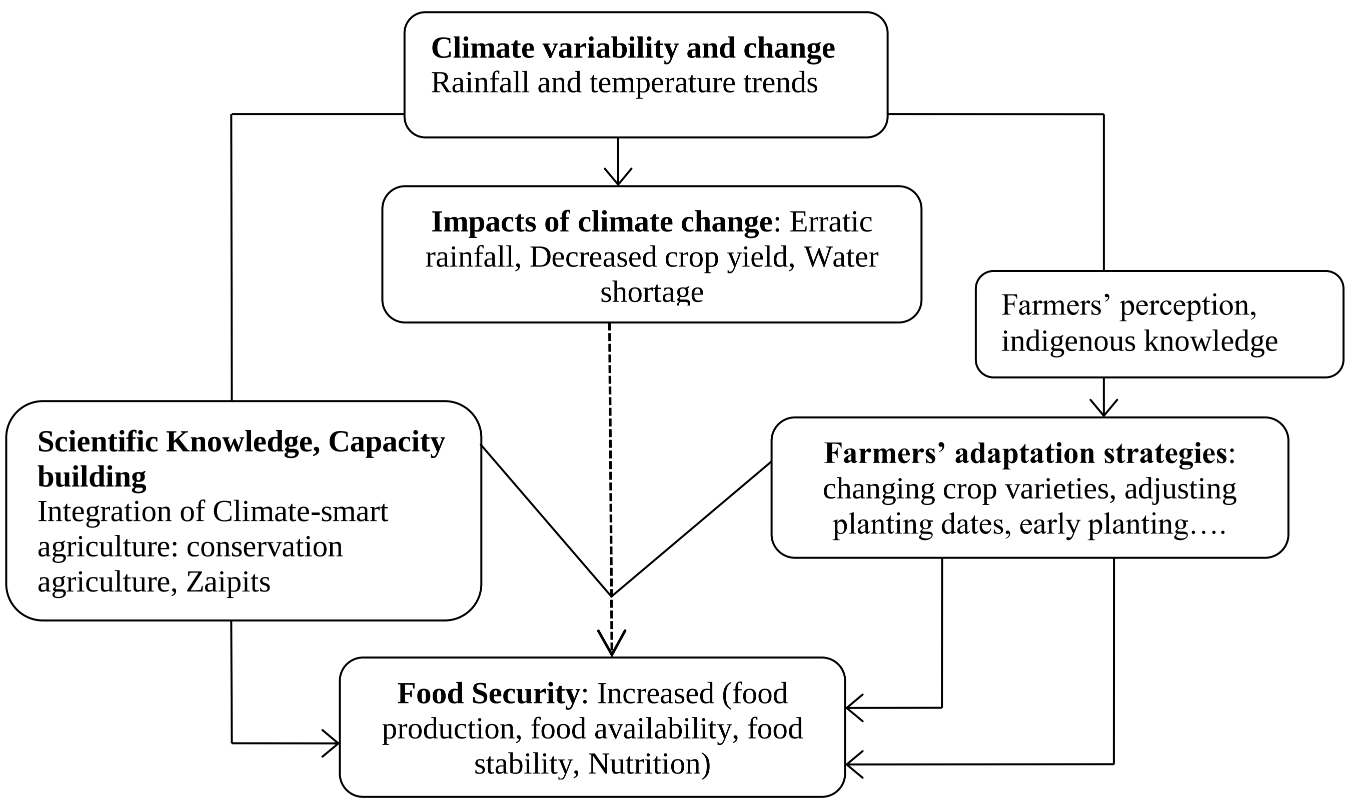


Figure 2: A Conceptual framework for pathway to Sustainable Food Security

(*Source: Author, 2017*)

3.4 Methods

This section outlines the methods used to achieve the study objectives. It is sub-divided into sections which describe various methods employed in the study including the data collection process, data sources, sampling strategy and sample size and data processing and analysis.

3.4.1 Data Collection Process

This sub-section outlines the steps followed during the survey data collection. It describes the reconnaissance (pre-visit) survey, recruitment and training of research assistants and pilot testing of the data collection tool.

3.4.1.1 Reconnaissance survey

Prior to commencement of the field research a reconnaissance survey of the study area was carried out. During the survey the researcher held sessions with selected groups of farmers, village leaders and agriculture ward officials to conduct a problem analysis in order to identify challenges experienced in relation to rural livelihoods in the locality. This was combined with stakeholder consultations to aid in the identification and selection of the CSA options to be incorporated into the farmers' systems towards solving the experienced challenges. In addition, farmers' awareness and capacity building on climate change, CSA principles and good agricultural practices (GAP) was incorporated into the sessions (Plate 1). This facilitated interaction with the community and was necessary to ensure suitability, adoption and ownership of the CSA practices by the farmers. Additionally, this interaction created an opportunity for the researcher to win peoples' trust and interest in support of the project as well as integrate them into the research process. Additionally, the survey was useful for the researcher to meet and interact with stakeholders and local informants as well as to introduce to them the study objectives. The stakeholders that were identified included: Ward agricultural officers, local administrators, representatives of selected farmers' groups, agrochemical dealers, and representatives of local NGOs and CBOs including Cereal Growers Association (CGA), Institute of Culture and Ecology (ICE), the World Vision, Christian Impact Mission (CIM) and Trainers of Trainers (ToTs) under a FAO-CA project, Agriculture, Marketing, Access and Linkages (AMAL).

Plate 1: **Farmers' sensitization session on benefits of CSA approaches**
Source: Author, 2016

3.4.1.2 *Recruitment and training of research assistants*

Since the research was participatory in nature, the researcher, with the help of local area guides, identified five research assistants/enumerators who were quite familiar with the study area and understood dynamics of the community very well. Prior to data collection, the research assistants were taken through a three-day training to aid them in understanding the objectives of the study, introduce the research tools and give a guideline on data capturing as well as aid them on how to translate any sensitive or difficult questions (Plate 2).

Plate 2: Training of enumerators on the research tool
Source: Author, 2016

3.4.1.3 Pilot testing of data collection tools

This was done prior to administering the research tools to check their suitability and reliability as well as ascertain capacity of the research assistants to administer the tools. The structured questionnaire was pre-tested with 20 farmers sampled from four villages, any ambiguity was noted and adjusted accordingly for accurate data capturing during the actual survey. The villages where farmers were included in the pre-test were eliminated from the actual sampling and further analysis. Furthermore, the questionnaire was always checked for consistency right after data collection in the field and any open issues or challenges experienced discussed and addressed.

3.4.2. Data Sources

This section outlines sources of the data and how data were obtained.

3.4.2.1 Secondary data sources

The first and third objectives of the study relied on secondary data which included climate and historical crop data (discussed below). Climate and crop data for the study area was obtained by reviewing existing databases from the respective National and County government offices. A thorough literature review was conducted to understand trends of climate variables in ASALs in

Kenya, experienced variability and changes in climate as well their impacts on farming systems and climate variables effects on specific crops.

Climate data: The study used climate data (rainfall and temperature variables) for a period of 31 years (1983-2014). The data was obtained from the Kenya Meteorological Department (KMD). According to the World Meteorological Organization (WMO, 2013) "use of 30-year period is considered long enough to filter out any interannual variation or inconsistency". According to IPCC (2007a), a 30-years period is eligible for the study of the relationship between climate variables and yields of food crops. The parameters obtained from the climate data included monthly totals from which seasonal and annual rainfall totals were computed, number of rainy days per month and monthly minimum and maximum average temperature.

Historical crop data: Historical crop data for maize and beans was obtained by reviewing seasonal/annual crop reports from the Yatta Sub-County agricultural offices at Kithimani. Data for the two crops was selected for the analysis because consistent crop area and yield data was found available from the year 1981 to 2013 which was an indicated that maize and beans were the major food crops grown in the area during this period. Data for each crop was obtained for the two cropping seasons in the area which depends on the long rains (MAM) and short rains (OND).

3.4.2.2 Primary data sources

The second and fourth objectives relied on primary data which was both qualitative and quantitative. The qualitative data was collected using focused group discussions (FGDs) while quantitative data was collected via a household survey using a structured questionnaire. The fifth objective relied on quantitative data which was collected using demonstration trials. The various data sources are discussed below.

Household Survey: A household survey was conducted by interviewing selected households in selected villages using a structured questionnaire. For each of the target locations, a facilitator native to the location was contacted a few days prior to the survey which helped to establish contact between the research team and the participants. The data collected from the household survey was further triangulated with data obtained from focus group discussions (FGDs). The questionnaire consisted of closed ended and Likert-scale questions; the closed ended questions were used to assess the household demographics and agriculture variables while the Likert scale questions were used to assess farmers' perceptions and opinions. According to Murray (2013), a Likert scale is a common tool to measure respondents' opinion, attitudes or perception. To ensure that the questionnaire captured data to address different aspects of the study, it was structured into five sections:

Section A and B captured questions on demographic profile (respondent's and household characteristics) and agricultural profile respectively. Although according to Denscombe (2010) "It is often stated that household variables should be put at the end of the questionnaire, this study considered to put the variables at the beginning of the questionnaire to build up trust and create a familiar atmosphere with the smallholder farmers. Section C captured questions meant to explore farmers' perceptions of climate variability and change. The respondents were asked to indicate their response in regard to any changes they had noted in variability and change in climate indicators, seasonal rainfall, temperatures and occurrence of dry periods over the last five years. A five point Likert scale (1-5), where 1=strongly disagree, 2= disagree, 3= not sure, 4= agree, 5= strongly agree was used.

Section D covered questions to understand which climate events had affected the farmers and their livelihoods and which coping measures they had adopted. In a five-point Likert scale (where, 1=not at all, 2= less extent, 3= moderate extent, 4= large extent, 5= very large extent), farmers were asked to state how the experienced climatic event had affected their livelihood, which coping measure(s) they had taken and to what extent the measure had improved their ability to cope with the experienced climate events. Lastly, Section E sought to explore measures (adaptation strategies) the farmers had adopted in relation to crop, soil and water management. Farmers were asked to indicate in a five point Likert scale (where 1=not at all, 2= less extent, 3= moderate extent, 4= large extent, 5= very large extent) the degree to which the adoption of these measures had improved their ability to cope with the experienced climatic changes. In the same section, farmers were asked to rate some of the factors that influenced their inability to implement desired changes in their farms.

Focus Group Discussions: Focus group discussions (FGDs) provide a useful instrument for gaining qualitative and in-depth information about a topic and can be used to complement quantitatively acquired information. Denscombe (2010) asserts that "use of different methods is useful because findings from one method can be contrasted with findings from another". This is what is referred to as 'methodological triangulation' where 'qualitative' data is compared with 'quantitative' data. This research conducted eight (8) FGDs using a structured guide (appendix 2) which was divided into sections addressing topics corresponding to those in the structured questionnaire.

The FGDS sought to understand farmers' perception of climate change and variability; garner a comprehensive understanding of climate change impacts to the community as well as understand farmers' responses in their farming systems to tackle challenges posed by climate variability and change. In each of the FGD session, farmers were divided into two groups and were allowed to discuss among themselves and later present their views and opinions to the entire group (Plate 3(a) and 3(b). This allowed for a closer interaction within the group where members were able to share and compare their contributions, experiences and thoughts which were helpful for getting a variety of responses on the research topic. According to Morgan (2006), "During focus group discussions members are able to share their experiences and opinions, while they can also compare their own thoughts to what others have said. Additionally, sharing and comparing responses is useful for hearing and understanding a range of responses on a research topic".

Plate 3(a): Farmers brainstorming exercise during FGDs breakout sessions
Source: Author, 2016

Plate 3(b): Farmers' brainstorming exercise during FGDs breakout sessions
Source: Author, 2016

On-farm demonstration trials: An experimental model research was conducted by setting demonstration trials (on-farm trials) at selected farmers' fields. A participatory action learning (PAL) approach was adopted where selected groups of farmers were integrated into the research (Plate 5). The reason for choosing this approach was to ensure that farmers took a center stage in planning and implementation of the trials. To ensure sustainability in adoption of the CSA models, smallholder farmers who participated in the study were encouraged to integrate the tested CSA practices into their farming practices as well as disseminate the acquired knowledge to their neighbors. Additionally, incorporating farmers into the research was also geared towards promoting indigenous, technical and social innovations as well as strengthening farmers' groups and team work. The experiments were aimed at comparing crop performance from the selected CSA models (CA and Zaipits) with the conventional tillage (CVT), for three consecutive cropping seasons. The cropping seasons were two OND seasons for the year 2016 and 2017 and one MAM season for the year 2017. At the end of every cropping season, final crop yield was harvested, measured and recorded.

Plate 4: Farmers' participating in planting of conservation agriculture plot
Source: Author, 2017

3.4.3 Sampling Strategy and Sample Size

A sample is a subset containing characteristics of a larger population. It constitutes a smaller set of observation units that are studied in order to draw conclusions about the entire population through statistical inference. According to Denscombe (2010), "a sample refers to sub-set of households or individuals taken out from the entire population under study". Cramer and Howitt (2004) define a sample as "a set of units drawn from a population in order to approximate the uniqueness of a population". According to Mugenda (2003), during sampling it is important to have a big sample that would aid to increase confidence of results obtained in a study. Other specific factors to be considered during sampling include homogeneity of the population, geographical dispersion/spread, logistics and accessibility, purpose of sampling and type of research design among others.

This study used a multi-stage sampling procedure which combined purposive and simple random sampling procedures. In the first stage, Yatta sub-county was purposively selected out of the eight sub-counties in Machakos County due to its extensive vulnerability to drought and further the sub-county was categorized on the basis of its five administrative wards. In the second stage, Ndalani ward was purposively selected from the five wards in the sub-county due to its ease of accessibility and the fact that less research findings in relation to climate change aspects had been recorded for the area. The ward consists of two locations; Ndalani and Mavoloni which consist of two and three sub-locations respectively. In the third stage of sampling, three sub-locations (Ndalani sub-location, KwaNdolo and Mavoloni) out of the five were selected then a list of the villages in the selected sub-locations obtained. The lists of villages were used as the sampling frame from which 46 villages out of a total of 88 were selected through simple random sampling. The study was then conducted in the selected villages (sample units) by means of a household survey, on-farm demonstration trials and FGDs. A description of how sampling was conducted for household survey, FGDs and on-farm demonstration trials is described below.

Sampling for FGDs and Demonstration trials

The farmers' groups and farmers who participated in the on-farm demonstration trials and focus group discussions (FGDs) respectively were selected using purposive sampling. The participating farmers in the FGDs were purposively selected to constitute experienced farmers who were native to the community and could thus provide useful information and valuable insights on how farming systems and climate in the locality had evolved over the years. A total of eight (8) FGDs were conducted in selected villages with each FGD constituting ten (10) farmers. Four (4) farmer groups each with thirty (30) farmers were selected to participate in the on-farm demonstration trials. The groups were selected using purposive approach to constitute groups that mainly focused on farming as the majority venture and had been in existence for at least three years.

Determination of sampling size for household survey

To determine a representative sample size for the survey, a statistical formula was used (Yamane, 1967). The formula determines a sample size from a specific predetermined population (P) at 95% confidence level and 5% degree of variability.

$n = \frac{N}{1} + N_e^2$ ………………………………………………………………………….Eqn (1)

Where:

n= Optimum sample size

N= Population size

e= Probability of error= 0.05

Computing the desired sample size using this formula gave an optimum sample size of 384 respondents. However, in order to cater for non-responses as well as cases of poor data capturing, the study considered a larger sample size of 400 households.

3.4.3 Experimental Design for Demonstration Trials

The on-farm demonstration trials were conducted on selected farmers' fields/plots. Each of the selected CSA model (conservation agriculture and Zai pits) was tested in comparison with the CVT in four farmers' demonstration trials which served as replicates. The trials took into consideration use of minimal tillage, drought tolerant seed varieties, herbicides, fertilizers/farm yard manure and pesticides for the CSA plots while assimilating use of conventional seed varieties and inorganic fertilizers for the CVT plots.

Conservation agriculture (CA) versus Conventional agriculture (CVT) Trials

The test crops used in the CA versus CVT plots were maize and greengrams each planted as a monocrop thus constituting four plots/treatments in each replicate (Figure 3). The measurement for each plot (replicate) measured 4,000m^2 subdivided into four treatments that were allocated to plots at random with each covering an area of a 1,000m^2. The treatments used in each replicate were as follows:

- CVT plots planted with a monocrop of maize
- CVT plots planted with a monocrop of greengrams

- CA plots planted with a monocrop of maize
- CA plots planted with a monocrop of greengrams

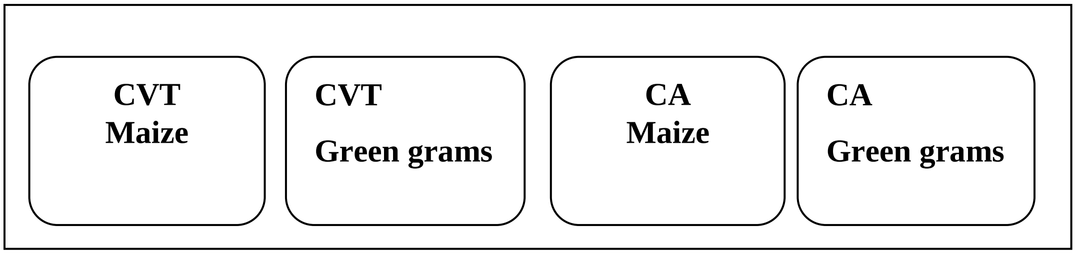


Figure 3: Experimental treatments (Conservation versus Conventional)

The CA field was ploughed using an oxen-drawn plough and soil was ripped in two passes. The first pass was done during dry season up to a depth of 15cm with spacing of 30cm between the rip lines (Plate 6) while the second pass was done through deep ripping up to 30cm at the onset of rains in order to break the hard pan. The aim of doing the second ripping was to increase water infiltration and reduce run off. The seed was then placed in the pass at the recommended spacing.

Plate 5: Tilling of conservation agriculture plot
Source: Author, 2017

Zaipits versus Conventional Trials

The test crop in the Zaipits versus CVT plots was maize planted as a monocrop thus constituting two treatments per each replicate (Figure 4). The measurement for each plots (replicate) was 2,000m^2 which was subdivided into two treatments which were randomly allocated to plots each covering an area of 1,000m^2. The treatments used in each replicate were as follows:

- CVT (Control) plots planted with a monocrop of maize
- Zaipits plots planted with a monocrop of maize

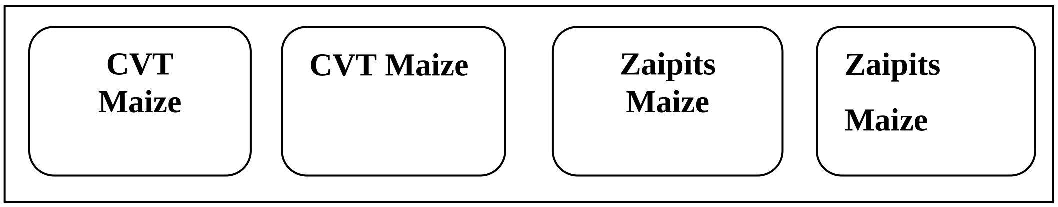


Figure 4: Experimental treatments (Zaipits versus Conventional)

The Zaipits were dug during the dry season (Plate 5) and then filled with two (20 kg) buckets farm-yard manure (corresponding to 1-3t/ha of dry organic matter), (Amede *et al*., 2011). They were planted with six seeds of hybrid maize after the onset of rains. On the other hand, the controls were planted using traditional farmers' seed after the onset of rains.

Plate 6: Zai Pits under Construction
Source: Author, 2016

Trials' Management

Every demonstration plot was managed by the participating farmers' with support from the agriculture extension officers who provided plot management recommendations while the researcher played the role of overseeing the trial sites, making technical recommendations and data collection. The varieties planted in the CSA plots were hybrid maize KDV1 and green gram KS20 while traditional farmers' seed was used for the CVT plots. Planting was done after onset of rains for both OND and MAM seasons. Recommended plant spacing was adopted for both maize and greengrams at 75cm by 25cm and 45cm by 15cm respectively. Weed management in the CVT and Zaipits plots was done manually whereas in the CA plots, weed management was done by first spraying with pre-emergence herbicide followed by manual weeding after emergence of secondary weeds.

3.4.4 Data Processing and Analysis

This section describes how the data was processed, analyzed and the softwares used for the analysis.

3.4.5.1 Climate data processing and analysis

Monthly temperature and rainfall datasets for a period of 31 years (1983 -2014) were used. The monthly values of rainfall and mean T_{max} and T_{min} were obtained from the KALRO Katumani agro meteorological station and these were used as insitu (ground) datasets.

Satellite dataset available in the GeoCLIM software was also used. The GeoCLIM software was used to extract the satellite data from the raster file and this was blend with the insitu station datasets. To obtain a more accurate gridded spatial data, the GeoCLIM was used to grid and blend the monthly rainfall and temperature datasets from both the satellite and insitu station observations at a horizontal grid resolution of 5km by 5km. The blended dataset was used because it is more accurate compared to the distinct datasets. The extracted dataset was then analyzed using XLSTAT computer software program to generate monthly, seasonal and annual trends of accumulated rainfall as well as monthly, seasonal and annual T_{max} and T_{min}. To determine seasonal rainfall trends over the period (1983-2014), seasonal data was quantified by calculating the total gridded rainfall data for the three months in each season of the year.

3.4.5.2 Estimation of Missing Climatic Data

Having some data values missing in a data set can bring vagueness into data analysis process thus which can affect properties of statistical estimators such as means, variances or percentages. To address this shortcoming, the study used multiple imputation (MI) to calculate the missing values from the insitu climate dataset. The MI methods generally assume that data are excluded at by chance, which requires that the probability of data being missing, conditional on observed data, is autonomous of the missing data (Buuren, 2007; Audigier *et al*., 2018). The MI generated multiple copies of the dataset and replaced the missing values by imputed values sampled from their posterior predictive distribution given the observed data. The MI method was chosen over single imputation and regression imputation methods because it is not prone to underestimation of the standard error and confidence intervals and since it fittingly corrects the standard error for the missing data.

3.4.5.3 Detection of rainfall and temperature trends

To determine rainfall and temperature trends, the data was subjected to both parametric and non-parametric data analysis. For parametric approach linear regression analysis was used. The regression analysis was used to verify the magnitude, direction and significance of the trends in annual and seasonal rainfall. The linear regression was fitted to generate a trend line and changes in temperature and rainfall described using the trend line equation (equation 2);

$Y = \beta_0 + \beta_1 X$ ………………………………………………………………….. Eqn (2)

Where "Y" represents the temperature (°C) or rainfall (mm) amounts, "β_1" represents the slope[1] which is the rate of change of the climate variable over the period and "β_0" represents the intercept on y-axis. The slope was used as a measure of how many units (rate of increase/decrease) the rainfall or temperature had gone up or down for every year or season. A negative gradient (slope) value implies a fall in the quantity of rainfall/temperature while a positive slope value specifies a raise in the amount of rainfall/temperature.

[1] The slope was used to show whether temperature and rainfall trends had declined or increased within the stated period.

The non-parametric approach, used the Mann-Kendall (MK) test to identify any changes (monotonic increasing or decrease) in rainfall and temperature trends (monthly, seasonal and annual) for the analysis period (1983-2014). The MK is an exceptional tool for detecting trends because data doesn't have to be normally distributed and thus it is less affected by existence of outliers and other types of non-normality (Pingale *et al*., 2016; Nalley *et al*., 2013).The MK test is based on calculation of Kendall's tau (measure of association between annual rainfall/temperature data for two consecutive years) and it searches for a trend in a time series without showing whether the trend is linear or non-linear" (Pingale *et al*., 2016).

The MK test is tested at 5% significance level with the resultant MK test statistic (S) indicating the strength of trend in temperature and rainfall and whether there is an increase or decrease in the trend. The null hypothesis (H_0) presumes that there is no trend which is tested against the alternative hypothesis (H_1) which presumes that there is a trend (either increasing or decreasing) in temperature and rainfall amounts over time. If the computed P-value is less than the significance level alpha (α=0.05), the null hypothesis is rejected which shows presence of significant trends in the time series while if computed P-value is larger than the significant level (α=0.05), H_0 is accepted which implies absence of significant trends in the time series.

Standard Precipitation Index (SPI)

SPI has been termed as a dominant, flexible and simple to calculate index which is used effectively in analyzing wet and dry periods/cycles (McKee *et al*., 1993). Its calculation is based on long-term rainfall data over a time period which is fitted to a probability distribution which is transformed into a normal distribution so that the mean SPI for the period is zero (Edwards and Mckee, 1997). Positive SPI values indicate precipitation which is greater than mean while negative values indicate precipitation which is less than the mean.

The SPI was calculated by subtracting the long-term mean from each observed value of the rainfall data (annual or seasonal) and dividing by the standard deviation (SD) as in the below equation:

$$SPI = \frac{Y - \bar{Y}}{s} \quad \text{Eqn (3)}$$

Where; Y = Actual rainfall (seasonal or annual) in a given year; $\bar{Y}$ = Mean annual rainfall over the total length of the period and s = Standard deviation for the total length of period. This produced standard mean annual rainfall scores that signify the number of SD above or below the mean that a specific observation falls. This was critical for purposes of visualizing time series variation of annual and seasonal (MAM and OND) rainfall about the mean.

Moving Average Trend Analysis

Moving average is a time series trend analysis method that makes use of averages of fixed number of items in the time series which move throughout the series by dropping the top items of the previous averaged group and adding the next in each successive average. This method was used to get rid of the short-term fluctuations in the mean annual rainfall time series and reduce the effect of extreme values while ensuring flexibility, objectivity and avoidance of bias of any estimator. Moving averages of order "k" are determined as;

$\frac{y_1+y_2+\cdots+y_k}{k}$; $\frac{y_2+y_3+\cdots+y_{k+1}}{k}$; $\frac{y_3+y_4+\cdots+y_{k+2}}{k}$ $e.t.c$…………………… Eqn (4)

Where $y_1+y_2+\ldots+y_k$; $y_2+y_3+\ldots+y_{k+1}$; $y_3+y_4+\ldots+y_{k+2}$ etc are the moving totals of order "k".

The most basic purpose of moving averages was to create a series of average values of different subsets of the full data set as described above. This naturally complemented the time series graphs interpretation by smoothening out the noise of random outliers and emphasizing the long-term trends. Moreover, the inherent variability exhibited by the rainfall time series masked the trends and periodic patterns. This led to smoothing of the time series so that the effect of random variations could be reduced and the trends and cyclical patterns enhanced.

3.4.5.4 Determination of crop yield relationship with climate variables

The relationship between crop yield (dependent variable) and the climate parameters (independent or predictor variables) was established using regression analysis. The analysis was performed on the mean crop yield (maize and beans) and climate data (rainfall, T_{max} and T_{min}) for a period of 30 years[2] (1983-2013). Analysis of how the climate variables had impacted crop yield was done on the seasonal data and not annual data in order to eliminate the high covariance arising from the dry spell seasons experienced in the year.

The functional relationship was described using the multiple linear regression model of the form;

$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \varepsilon$ ………………………………….Eqn (5)

[2] The 30-year period was based on concurrent data for both climate and crop for 1983-2013

Where; Y = Crop yield (dependent variable)

X_1 = Rainfall

X_2 = Maximum temperature

X_3 = Minimum temperature

β_0 = Regression constant

$\beta_1, \beta_2, \beta_3$ = Regression coefficients/slopes

ε = Random error component

The regression constant in the model indicate the amount of a given crop yield that was not influenced by the three independent/predictor variables within a given season. On the other hand, the regression coefficients were used to establish the amount of change in the dependent variable per unit change in a given predictor/independent variable.

3.4.5.5 Goodness of fit of the regression models

Various statistical procedures were used to assess the goodness of fit of the linear regression model developed. These included; the adjusted coefficients of determination (Adjusted R^2), the Durbin Watson statistics, the F-statistics, P-Values, t-statistics and the Variance Inflation Factors (VIFs).

Coefficient of Determination (R^2): Coefficient of Determination also referred to as the explanatory power of a regression model, is a measure of the proportion of variation in the response variable that can be explained by the model. Adjusted R^2 was used to assess the explanatory power of the model by calculating the proportion of the variations in the indicators of the response variables that could be explained by the developed models. $1 - R^2$ gives the unexplained variation, which is mostly associated to pure chance variations and other important predictor variables that may be were not been captured by the analysis/models (Colin and Windmeijer, 1997). In this case, the higher the value of Adjusted R^2, the stronger the model, and vice-versa. Specifically, using the rule of the thumb; if $R^2 \geq 75\%$, the model is excellent, if $60\% \leq R^2 \leq 74\%$, the model is good, if $50\% \leq R^2 \leq 59\%$, the model is satisfactory and if $R^2 \leq 49\%$, the model is poor.

Autocorrelation: The term "correlation" refers to a correlation between units, and the prefix "auto" refers to a distinct variable being related to itself (Griffith, 1984). The observations of the variables in a regression model are required to be statistically independent. Dependence or interaction among the observations of a given variable is referred to as autocorrelation or serial correlation. To assess the presence or absence of autocorrelation, the Durbin Watson statistic (*d)* was computed; $d \simeq 2$ indicates absence of autocorrelation.

Significance of the model as a whole: Regression Analysis of Variance (Regression ANOVA) was performed on the model in order to test for the statistical significance of the model and its adequacy for prediction, The ANOVA expedites the Fisher's test (F-test) which uses the F-statistic as the test statistic. F-statistic is the ratio of the explained variation to the unexplained/residual deviation. This procedure tests the hypotheses;

Null hypothesis (H_0): The model is NOT statistically significant, against;

Alternative hypothesis (H_1): The model is statistically significant.

The computed F-statistic is compared with the critical F-statistic at the specified significance level; 5% for this study. The null hypothesis (H_0) is rejected if computed F-statistic ≥ critical F-statistic, or if the P-value is less than the significance level i.e. 0.05.

Significance of the explanatory variables: To test the statistical implication of the individual predictors in the models, t-tests were performed. Barrett & Goldsmith (1976) examined the adequacy of the t-test in three small data sets and found that it is adequate for tests on samples of size 40 or more. T-test uses the t-ratio/statistic as the test statistic. T-statistic is the ratio of the projected regression constant to its standard error. A regression constant with a high standard error yields a small absolute t-statistic rendering it to be non-significant. This implies that the higher the absolute t-statistic, the stronger the predictor variable and vice-versa. t-test tests the hypotheses;

Null hypothesis (H_0): $\beta_i = 0$ (The predictor variable is NOT statistically significant), against,

Alternative hypothesis (H_1): $\beta_i \neq 0$ (The predictor variable is statistically significant).

The computed t-statistic is compared with the critical t-statistic at the specified significance level. This is a two-tailed test which requires that the critical t-statistic is obtained at half of the significance level, in this case, 2.5%. The null hypothesis is rejected if, computed |t-ratio| ≥ critical t-statistic, or if the P-value is less than the significance level i.e. 0.05.

Collinearity: Collinearity (or multicollinearity) is the presence of a statistically significant linear relationship between two or more predictor variables (independent variables) in a regression model. Existence of collinearity in a regression model compromises the explanatory power of the model rendering it insignificant and inadequate for prediction (Coakes *et al*., 2008). Thus, a regression model is deemed to be statistically significant if its predictors are non-collinear. To assess whether any predictors in a regression model were collinear or not, Variance Inflation Factor (VIF) was computed for each predictor. Collinearity yields highly inflated variances, where a given variance is said to be significantly inflated if VIF ≥ 10.

Homoscedasticity: An important assumption in linear regression analysis is that of homoscedasticity or homogeneity of variance (Rencher, 2000; Fox, 2008; King *et al*., 2010). Homoscedasticity is the property of the residuals of least squares regression model having equal variances, which is a requirement for a statistically significant model. The contrary is referred to as heteroscedasticity. The Breusch-Pagan (Bp) test which follows a Chi-square distribution was used to test for homoscedasticity of the residuals with the number of regression parameters in a model less one as the degrees of freedom. The procedure tests the hypotheses;

Null hypothesis, H_o: the variance is constant (residuals are homoscedastic), against

Alternative hypothesis, H_1: the variance is not constant (residuals are heteroscedastic)

The decision rule requires that the null hypothesis is rejected if and only if the computed test statistic *(Bp statistic)* is greater or equal to the critical test statistic from the Chi-square distribution table at the specified significance or confidence level and the determined degrees of freedom.

3.4.5.6 Processing and Analysis of Questionnaire and FGDs data

The household questionnaire was administered using drop-and-pick method in order to ensure reliability, follow-up and maximization of response rate. In situation where the respondent was not able to fill the questionnaire due to inadequate literacy level, the enumerators offered to take the respondent through the entire questionnaire while filling the respondent's responses. At the end of every day, verification of the questionnaires was done to confirm for completeness and consistency and thereafter the collected data was cleaned, edited and organized in readiness for analysis. The questionnaire data was coded using Statistical Package for Social Scientists (SPSS) and MS Excel for further data management, analysis and presentation. For the purposes of data description, descriptive statistics of the key variables were computed.

The questionnaire data was assessed for reliability using the Cronbach's Alpha Coefficient to determine the effectiveness of the questionnaire as a data collection instrument for the study. The demographic characteristics of the respondents were examined using frequencies and percentages which revealed the representation of each quota in the sample ranging from gender, age brackets, duration lived in the study area, education level, members in a household, and sources of income. These descriptive statistics were accompanied with graphical presentations in form of tables and charts to enhance summaries, comparisons and quick interpretation of the data. Chi-square statistics were computed in various segments in order to examine the dependency and association between various demographic characteristics. The statistics enabled the Chi-Square non-parametric tests of independence at 5% significance level. Similar approaches were used in describing the data on agricultural profiles where frequencies, percentages, tables and charts were used and Chi-square statistics to test for association between various agricultural variables.

All FGDs discussions audio files were transcribed and verification for each script done by comparing field notes to the transcribed scripts. Data entry, cleaning and coding was then done using emerging themes. The major themes in all transcripts were further coded into sub-themes which were then clustered together using comparable topics. The FGD responses were then triangulated with the corresponding responses from the relevant sections of the questionnaire..

3.4.5.7 Chi-Square test for independence

Chi square test (χ^2) for independence is a non-parametric test that assesses the association between two attributes of a population (Kothari, 2007). The test analyses cross-sectional to investigate the null hypotheses that the attribute represented by the columns is independent of the attribute represented by the rows and vice versa, against a contrary alternative hypothesis. The test statistic, $\chi^2_{computed}$, is based on the frequencies and is computed as follows:

$$\chi^2_{computed} = \sum_{i=0}^{n} \frac{(\theta_i - \epsilon_i)^2}{\epsilon_i} \quad \text{......Eqn (6)}$$

Where;

$\theta \equiv The\ observed\ frequency$

$\epsilon \equiv The\ expected\ frequency$

$n \equiv The\ number\ of\ observations\ (n = r \times c)$

$r \equiv Number\ of\ rows$

$c \equiv Number\ of\ columns$

The critical statistic for the test, $\chi^2_{critical}$, is usually obtained from the Chi-Square distribution tables at the specified significance level and the existing degrees of freedom i.e.

$\chi^2_{critical} = \chi^2_{\alpha,v}$ ……………………………………………………………………Eqn (7)

Where;

$\alpha \equiv Significance\ level$

$v \equiv Degrees\ of\ freedom, computed\ as;$

$v = (r-1) \times (c-1)$

Being a one-tailed and positively skewed hypothesis test, the decision rule of the test requires that the null hypothesis is rejected if $\chi^2_{computed} \geq \chi^2_{critical}$

3.4.5.7 Analysis of the Likert Scale data

Likert data was analyzed using frequencies, percentages and measures of central tendency; mean and mode. The frequencies and percentages helped in bringing out the actual distribution of the responses among the Likert scale items thus exposing the general skewness and tendency of the responses. The arithmetic mean gave the average feeling of the respondents by giving the most central measure of all responses given. For instance, a mean of 4 would indicate that the respondents generally "agreed" to the Likert item in question, while a mean of 5 would indicate that the respondents generally "strongly agreed" to the item, despite the variations in the individual responses. Mode is the most popular, most frequent or most repeated observation and thus it gave a clear indication of the feeling of the majority of the respondents for each variable.

3.4.5.8 Processing and Analysis of the Experimental Data

The Crop yield data obtained from the experiments demonstration plots was organized and analyzed using MS excel to generate means from the various treatments. Any statistically significant differences between the means of crop yield from the two treatments (two different types of farming methods- CSA and CVT) in each season were tested using one way/single factor analysis of variance (ANOVA). The null hypothesis (Ho) tested was: There is no significant difference between CSA and CVT methods, against H_1: There is significant difference between CSA and CVT methods.

The ANOVA was conducted at 5% significance level, in which case the decision rule to reject the hypothesis of 'no significant difference between the effects of the treatments' was based on the P-value as well as the computed F-statistic. The Hypothesis was rejected where the P-value was less than the significance level, and the computed F-Statistic greater than or equal to the critical F-Statistic.

3.4.5.9 One-Way/Single Factor Analysis of Variance (ANOVA)

The ANOVA was used to examine the difference between the effects of various treatments by comparing the means of two groups on the dependent variable (Green and Salkind, 2012). One-Way/Single Factor Analysis of Variance (ANOVA) is a quantitative analysis technique which evaluates whether different types of a given treatment yield significantly different results, given that all other factors are held constant. This type of ANOVA investigates the null hypothesis that there is no statistically significant difference against a contrary alternative hypothesis. The test statistic is usually referred to as the F-statistic and is computed from the mean sums of squares as follows;

$F_{computed} = \frac{MSS_{BG}}{MSS_{WG}}$……………………………………………………………Eqn (8)

Where;

$MSS_{BG} = Mean\ Sum\ of\ Squares\ between\ Groups, computed\ as;$

$MSS_{BG} = \frac{SS_{BG}}{k-1}, where\ k-1\ \equiv degrees\ of\ freedom\ between\ groups$

$MSS_{WG} = Mean\ Sum\ of\ Squares\ within\ Groups, computed\ as;$

$MSS_{WG} = \frac{SS_{WG}}{r-1}, where\ r-1\ \equiv degrees\ of\ freedom\ within\ groups$

The critical statistic, $F_{critical}$, is obtained from the F (Fishers') distribution tables at the specified significance level and the existing degrees of freedom i.e.

$F_{critical} = F_{\alpha,k-1,r-1}$ ……………………………………………………………Eqn (9)

The decision rule then requires that the null hypothesis is rejected if, $F_{computed} \geq F_{critical}$.

*All analysis was done using MS Excel Tool Pak and SPSS Statistics Version 23.

CHAPTER FOUR: ASSESSMENT OF RAINFALL AND TEMPERATURE TRENDS

4.1 Introduction

This chapter presents results and detailed discussions of the first objective of the study. Sections 4.2 and 4.3 provide result and interpretation of outputs from the analysis of rainfall and temperature trends respectively. Section 4.4 shows the determination of statistically significant trends of rainfall and temperature using Mann-Kendall Test.

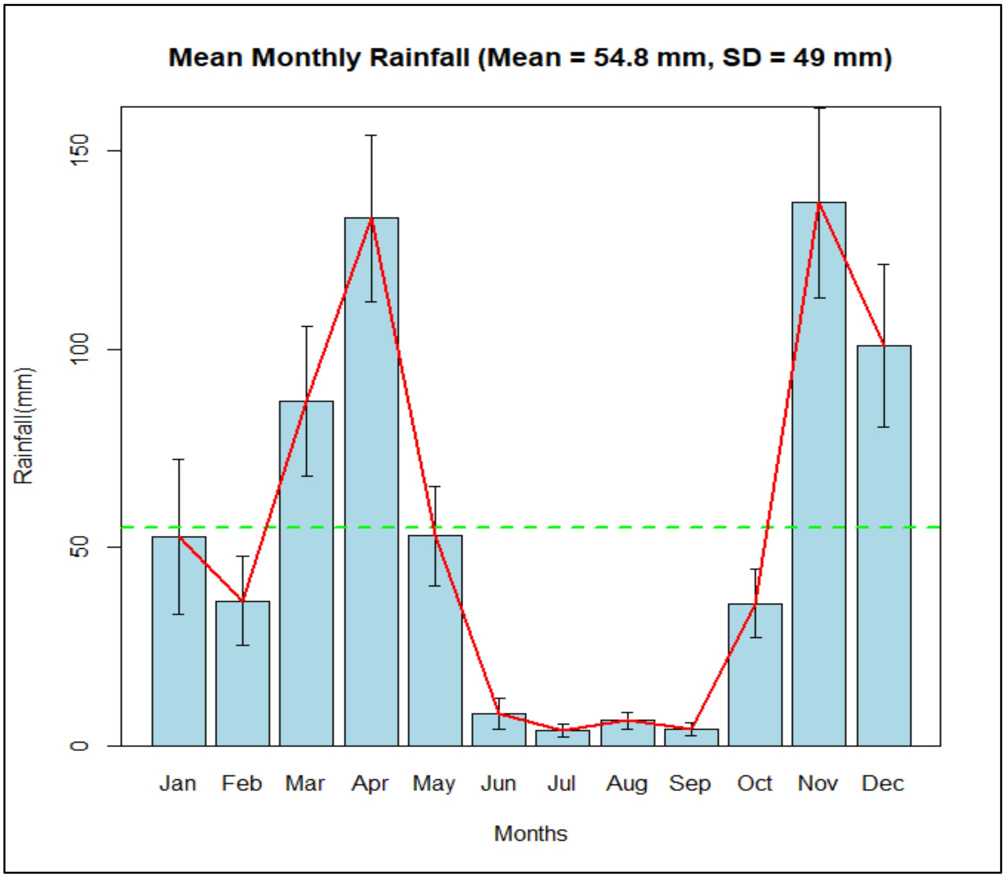
4.2 Rainfall trends

This section outlines the analysis results of monthly, seasonal and annual rainfall amounts recorded in the area over the period 1983-2014.

4.2.1 Annual-Monthly Rainfall Variation

Analysis of average monthly rainfall was done to show mean monthly rainfall variation in the study area in the period of thirty one years (1983-2014). The analysis showed that there are two rainfall seasons that peak from March to May (MAM) and October to December (OND) with April and November being the peak months in terms of rainfall amounts (Figure 5). The months within the MAM and the OND seasons were observed to be wetter, with the months of June, July, August and September being the driest while January and February received moderate rainfall. This is a clear indication that the area experiences a bimodal rainfall pattern distributed in 'two typical rainy periods' referred to as the 'long rainy season' occurring in March, April and May (MAM) and the 'short rainy season' occurring in October, November and December (OND). The results indicate that the overall monthly mean rainfall recorded was 54.8 mm with a standard deviation of 49 mm. The short rains (OND) recorded slightly higher monthly average of 91.14 mm as compared to the long rains (MAM) which recorded monthly average of 90.87 mm. This is contrary to expectation as the long rainy season would be expected to have higher average rainfall compared to the short rains. On the other hand, June, July, August and September as well as January and February depict dry seasons by recording minimal monthly averages of rainfall amounts. A similar pattern was observed in a report by Herrero *et al*. (2010) which analyzed monthly rainfall variation of the monthly total rainfall in Makindu which lies within the same geographical area as the study area.

Figure 5 shows the variation of the annual variation of the mean monthly rainfall over Yatta between 1983 to 2014.



P-Value = 4.23E-05, F-Value = 30.110

Figure 5: Mean monthly rainfall variation (1983-2014)

The mean monthly rainfall indicated statistically significant variation with P-Value = 4.23E-05 and F = 30.11 at 5% significance level.

4.2.2 Seasonal rainfall trends

As described in Chapter three, section (3.2.4), the area experiences a two seasons 'bimodal' rainfall pattern. Figure 6 shows the seasonal rainfall trends for the study area over the period 1983-2014. The graph demonstrates that generally, OND season has slightly higher rainfall than the MAM season. The highest rainfall in the OND season were recorded in the years 1994, 1997 and 2006 with seasonal totals of 650.9 mm, 571mm and 660.9 mm respectively while the lowest rainfalls were experienced in 1983, 1984 and 1998 with seasonal totals of 105.8 mm, 57 mm and 133 mm respectively. On the other hand, the highest rainfalls in the MAM season were recorded in the years 1985, 1990 and 2010 with seasonal totals of 441.6 mm, 533.7 mm and 470.7 mm respectively, while the lowest seasonal rainfalls were recorded in 1984, 1987 and 1993 with seasonal totals of 55.4 mm, 119.4 mm and 95.4 mm respectively. These results indicate that the amount of rainfall in the study area is extremely variable though exhibiting increasing trends in the two rainy seasons. The MAM season recorded a higher rate of increase (3.12 mm p.a) in seasonal rainfall levels as well as a higher coefficient of variation (CV) of 6.38%. The OND season recorded a lower rate of increase (1.31 mm p.a) with a CV of 0.75%. The coefficients of variation indicate that the OND season has a lower contribution to the annual rainfall variability. The increased seasonal variation and rainfall amounts in the MAM season confirm a report by Awour (2009) which indicates that in the Eastern province of Kenya, the long rains have become increasingly erratic, unreliable and more intense and last only for a shorter period of time. The increase in rainfall variability in terms of timing and amount: including delay or shifts in the onset and/or cessation of both long and short rainy seasons, long or short dry spells and sometimes even loss of entire season has led to increased climate risks in Kenya (Conway and Schipper, 2011; Aberra, 2012).

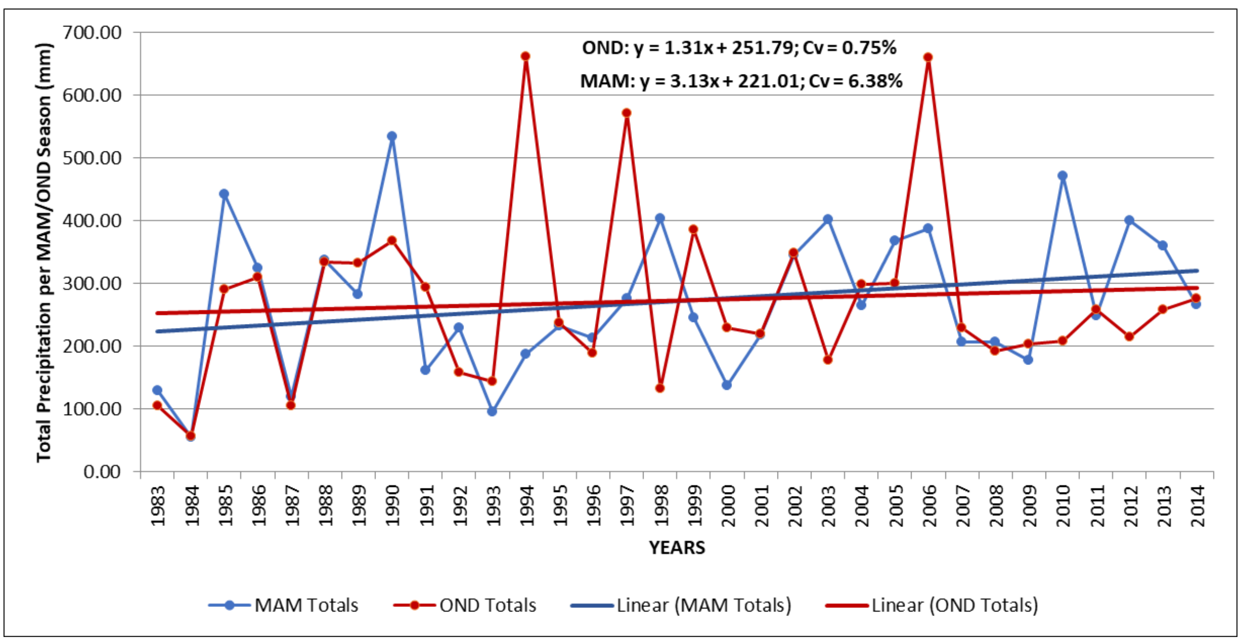


Figure 6a: Trends of seasonal (MAM & OND) rainfall (1983-2014)

Figures 6(b) and 6(c) show the annual variation of the standardized monthly mean rainfall for the MAM and OND seasons respectively. The mean monthly rainfall for the MAM season was 90.87 mm with SD (38.73 mm), while the mean monthly rainfall for the OND season was 91.14 mm with SD (47.26 mm). This shows that on average, monthly rainfall was higher during the OND season than during the MAM season. The variation in monthly rainfall was found to be statistically significant during both seasons, with the OND season recording higher variation (P = 7.58E-08, F = 19.658) than the MAM season (P = 6.67E-06, F = 13.584). The results show that both seasons experienced seasonal rainfall variability while recording 18years of below normal rainfall and 14years of above normal rainfall for each season.

However, the MAM season was observed to be generally wetter than the OND season with the graph showing more positive bars for MAM season reaching 1 mm standardized mean rainfall, unlike the OND season which showed only 3 years recording above 1 mm standardized mean rainfall. On the other hand, the MAM seasons experienced more drier periods than the OND season. This is explained by the 10^{th} percentile for the MAM season which is below -1 mm standardized mean rainfall unlike for the OND season where the 10^{th} percentile is approximately at -1 mm standardized mean rainfall. Also, the negative bars for the MAM season run beyond -1 mm standardized mean rainfall unlike for the OND season. Notably, the year 1984 recorded the driest MAM rains which confirm similar findings by Recha *et al*. (2012) which established that the MAM season rains in the year 1984 to have been the driest in Tharaka Nithi District.

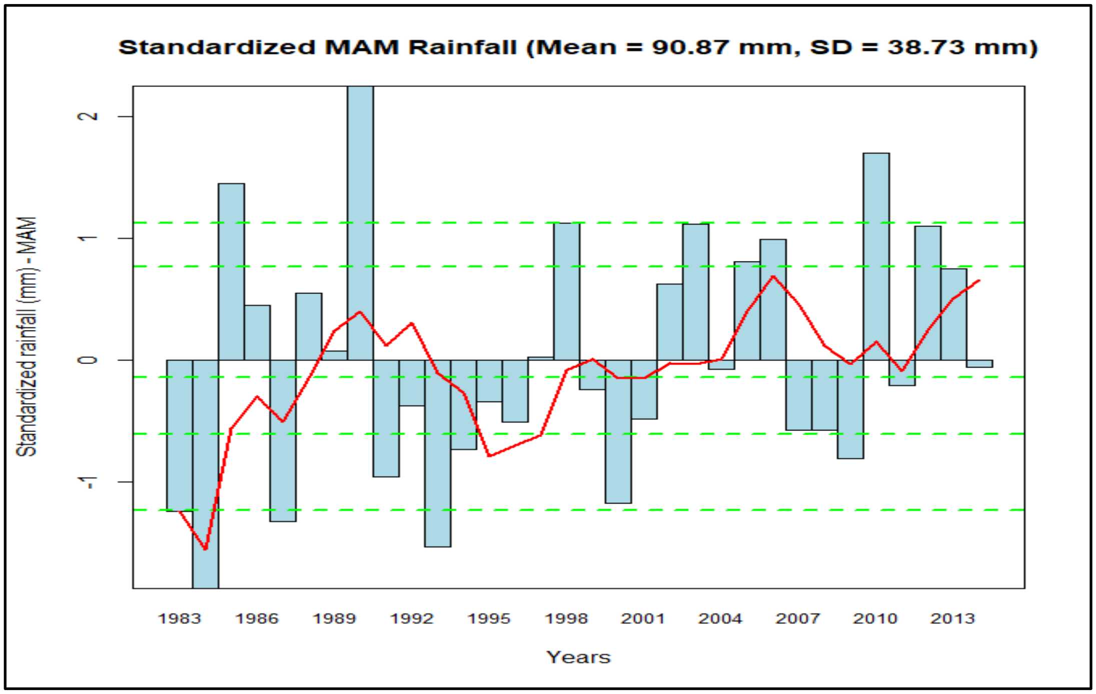


Figure 6(b): A time Series of Standard precipitation index (MAM Season) for 1983-2014

*Dashed horizontal green lines are the 10, 25, 50, 75 and 90th percentiles of the frequency distribution of rainfall normalized to zero mean. *Solid red lines are the 5-year moving averages of standardized rainfall component

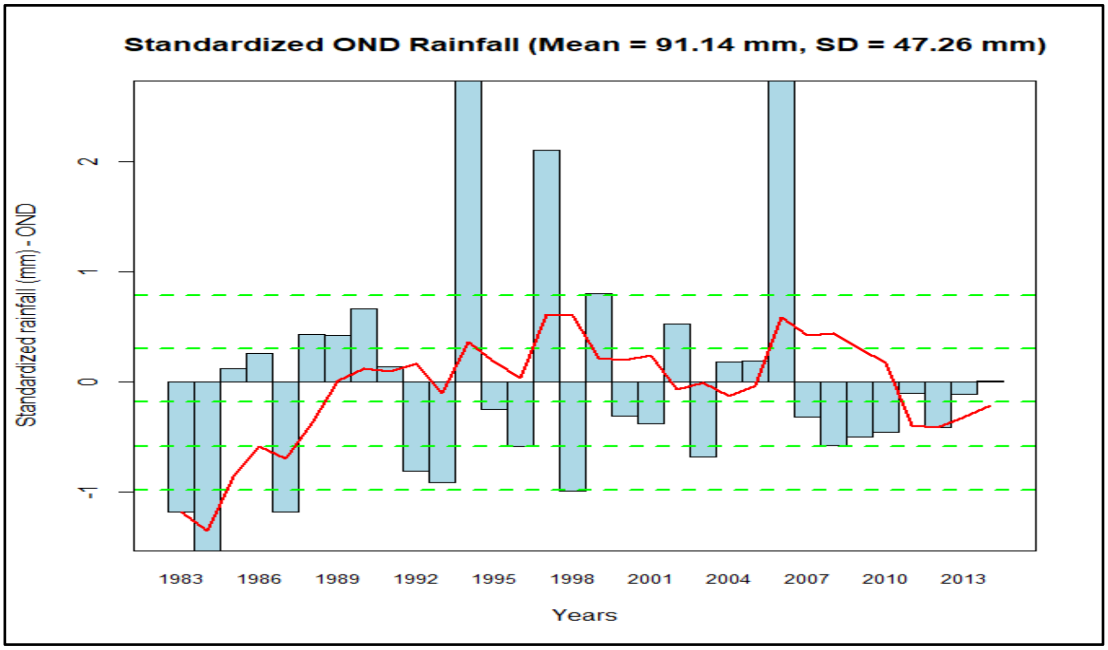


Figure 6(c): A time series of standard precipitation index (OND Season)

*Dashed horizontal green lines are the 10, 25, 50, 75 and 90th percentiles of the frequency distribution of rainfall normalized to zero mean. *Solid red lines are the 5-year moving averages of standardized rainfall components.

4.2.3 Annual rainfall trends

Annual rainfall data was analyzed to determine annual rainfall trends and variability. Figure 7a shows the annual rainfall trends for the study area over the period 1983-2014. Results of the inter-annual rainfall trends in the study area showed that the average annual rainfall experienced over the 32-year period (1983-2014) was 657.1 mm. It is observed that the area experienced 18 years of above average rainfall and 14 years of below average rainfall over the analysis period. The lowest amounts of annual rainfall were recorded in 1984, 1987 and 2000 with total annual rainfall of 165.7mm, 334mm and 383.8 respectively, while the highest amounts of annual rainfall were recorded in 1990, 1998 and 2006 with total annual rainfall of 975.7 mm, 990.2 mm and 1154.6 mm respectively. The results further indicated an annual rate of rainfall increase of 3.79 mm p.a and with a CV of 2.79%.

These results confirm a report by Herrero *et al*. (2010) which indicated that flash floods were experienced in the ASALs of Kenya in the year 1998 as well as 2006. From the results, it is evident that the area has been experiencing an erratic rainfall pattern during the 32-year period though with a generally increasing trend. In addition, the graph shows that a year of heavy rains (above average rainfall) is usually preceded by one or two years of low rains (below average). Similar results of increasing annual rainfall trends were obtained from an analysis of rainfall variability over decadal timescales for five locations of the semi-arid region of Kenya (Kitui, Mwingi, Mutomo, Machakos and Makueni) (Rao *et al.* (2011). The results showed that rainfall for the past two decades (1986-2005) was equivalent or slightly higher than the rainfall during the previous two decades (1966-1985). The increasing annual rainfall trends could possibly further explain the outcome of rainfall projection models which indicates an increase in mean annual rainfall in arid districts of Kenya. The projections indicate that increase in total rainfall will be largest in the OND season but annually these increases will be in the order of 20-40mm per year (KNMI, 2006).

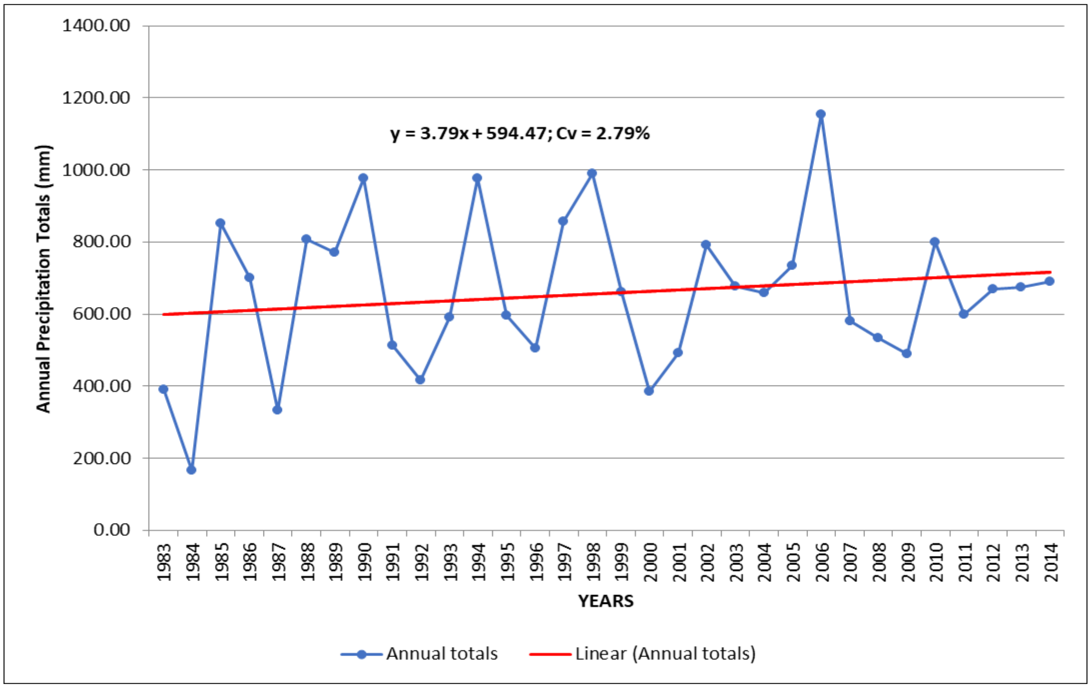


Figure 7(a): Annual rainfall trends (1983-2014)

Figure 7(b) shows the standardized mean annual rainfall for the period 1983 to 2014.

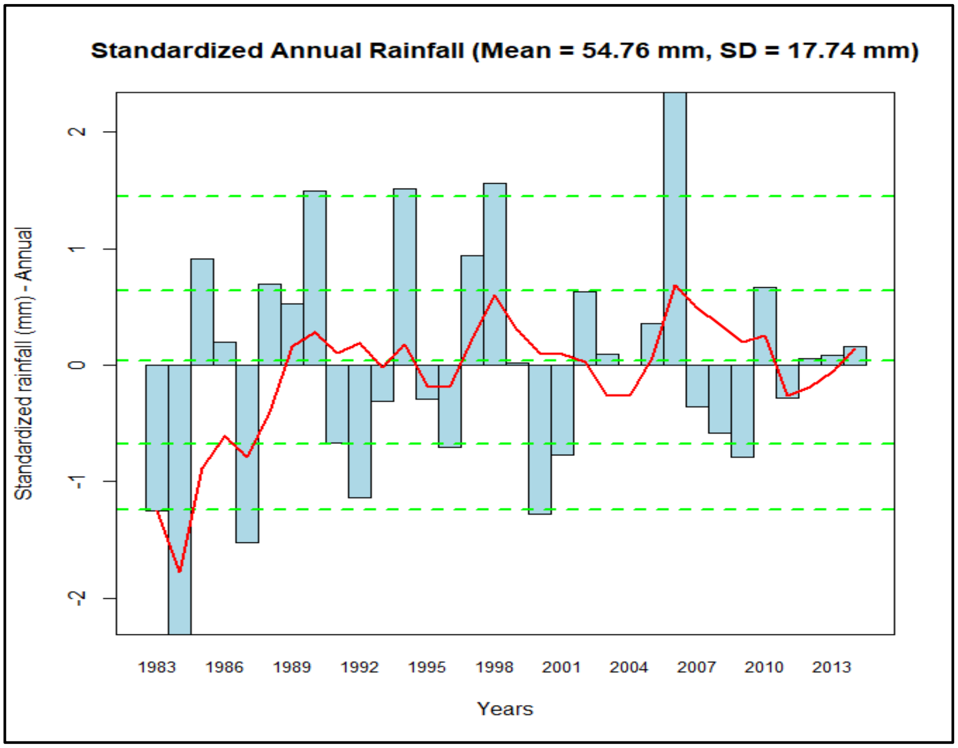


Figure 7(b): A time series of annual standard precipitation index (1983-2014)

*P-Value= 0.779; F-Value = 0.793;

*Dashed horizontal green lines are the 10, 25, 50, 75 and 90th percentiles of the frequency distribution of mean annual rainfall normalized to zero mean. *Solid red lines are the 5-year moving averages of standardized rainfall components

The overall mean of the standardized annual rainfall was 54.76 mm with a standard deviation of 17.74 mm. The mean annual rainfall showed statistically insignificant variation with P-value (0.779) and F-value (0.793). It was observed that 14years experienced annual rainfall that was below normal while 18years experienced annual rainfall that was above normal over the 32-year period. The five-year moving average shows a persistent high variability of the annual rainfall over the period which is an indication that variability and change in climate is happening in the study area. It was further observed that the year 1984 and 2006 were outliers recording extreme rainfall amounts of lowest and highest respectively. This confirms findings by Herrero *et al*. (2010) which showed that flash floods were experienced in Kenyan ASALs in the year 2006 and also report by Hutchinson (1996) and Shisanya (1990) which have documented that a severe drought was experienced in Kenya in the year 1984.

Figure 8 shows the mean annual rainfall moving averages for the period 1983 – 2014.

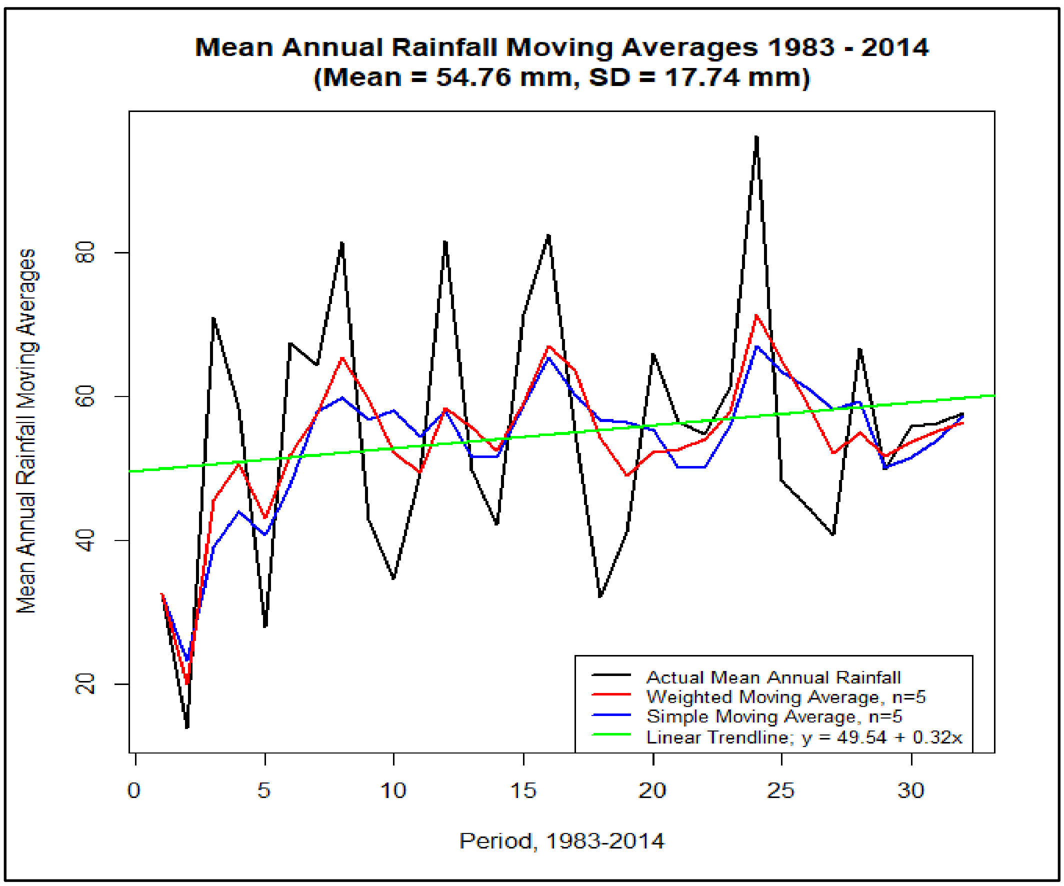


Figure 8: Moving average for mean annual rainfall for the period 1983 – 2014

*The blue circles show the identified cyclical variations on both weighted and simple moving averages.

The actual mean annual rainfall was observed to exhibit a lot of "noise" over the 32-year period (1983 – 2014). However, the moving averages smoothens the graph thus reducing the "noise" in order to enhance the general trend of the annual rainfall. From both the simple and weighted moving average graphs, the mean annual rainfall was observed to have recorded a gradual increase by showing a positive/upward trend which is emphasized by the linear trendline with an intercept of 49.54 mm and a positive slope of 0.32 mm per annum. Cyclical variations/fluctuations are movements that are observed in a timeseries with time intervals that are greater than one year. Both the weighted and simple moving averages (n = 5) show some cyclical variations where the mean annual rainfall is exra-ordinarily higher in a specific year which is generally after every 7 years. These cyclical movements are observed around the 7^{th}, 16^{th} and the 24^{th} year (years 1989, 1998 and 2006).

4.3 Temperature trends

This section illustrates monthly temperature trends as well as minimum (T_{min}) and maximum (T_{max}) seasonal and annual temperature trends.

4.3.1 Annual maximum and minimum temperature trends

The trends in the annual T_{max} and T_{min} levels are illustrated by Figure 9(a) and 9(b) respectively. It was observed that the highest annual T_{max} was recorded in years 1987, 2000, 2009 and 2011 at 25.93°C, 26.38 °C, 25.87 °C and 26.06 °C respectively, while the lowest annual T_{max} were recorded in years 1985, 1989, 1990 and 1998 at 24.18 °C, 24.21 °C, 23.33 °C and 24.54°C respectively. On the other hand, the highest annual T_{min} were recorded in years 1983, 2011, 2013 and 2014 at 13.93 °C, 14.16 °C, 14.03 °C and 14.10 °C respectively, while the lowest annual T_{min} were recorded in years 1989, 1995, 1996 and 2003 at 12.50 °C, 12.71 °C, 12.62 °C and 12.64 °C respectively. It was further observed that both annual T_{max} and T_{min} portrayed upward trends over the period. The rate of increase in annual T_{max} was 0.02 °C p.a with a variation of 16%, while the rate of increase in annual T_{min} was 0.02 °C p.a but with a variation of 31%. These results concur with other findings which have shown that annual temperatures in Kenya have increased by 1.0°C since 1960, with an average rate of 0.1°C per decade (McSweeny *et al*., 2009; Christy *et al*., 2009). Other findings have also showed that there is an increased variability in extreme temperature events such as extreme T_{max}, warm days, warm night and duration of warm spells (Omondi *et al*., 2014, IPCC, 2007a). The findings are also in agreement with IPCC (2014b) report which predicted an average temperature increase of 0.2°C per decade in Kenya.

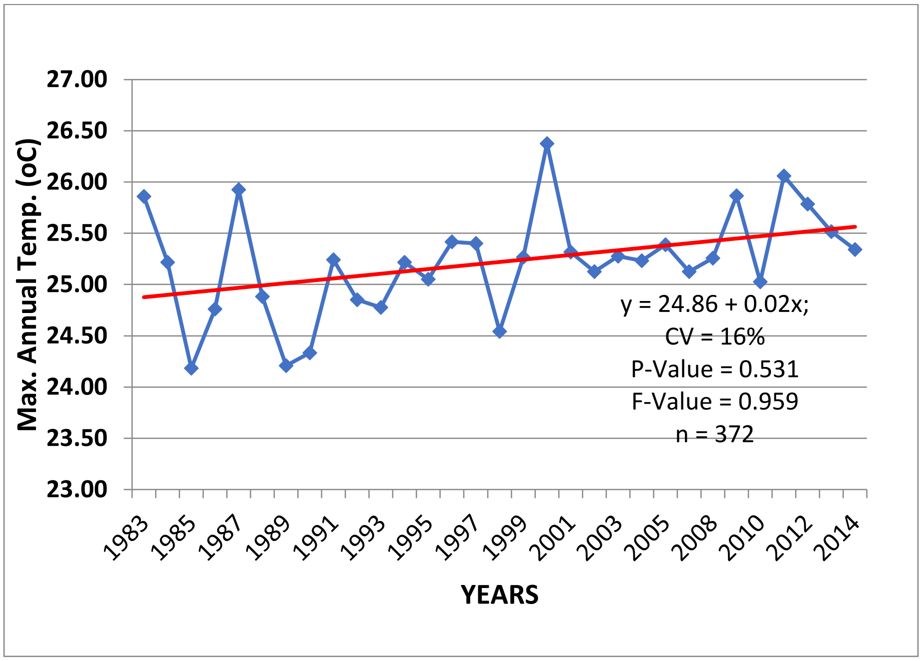


Figure 9(a): Annual maximum temperature trends (1983-2014)

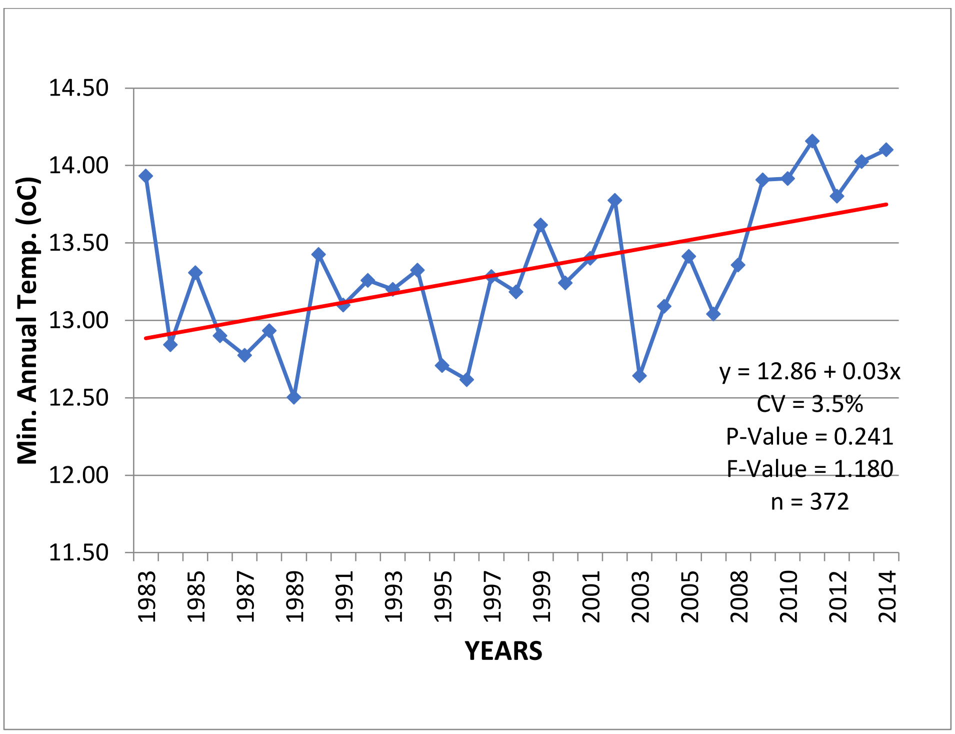


Figure 9(b): Annual minimum temperature trends (1983-2014)

Table 4: Absolute increase in maximum and minimum temperature (1983 – 2014)

	Period	Equation	Year	Recorded (ºC)	Change (ºC)
Maximum	Annual	Y = 24.855+0.0228x	1983	24.88	0.71
			2014	25.58	
	OND	Y = 24.872+0.0099x	1983	24.88	0.31
			2014	25.19	
	MAM	Y = 25.929+0.0103x	1983	25.94	0.32
			2014	26.26	
Minimum	Annual	Y= 12.855+0.0288x	1983	12.88	0.89
			2014	13.78	
	OND	Y = 13.706+0.03x	1983	13.74	0.93
			2014	14.67	
	MAM	Y=14.160+0.0261x	1983	14.19	0.81
			2014	15.00	

The total increase in mean annual maximum temperature between 1983 and 2014 was 0.71ºC while the mean T_{min} increased by a rate 0.89 ºC over the same period of time (Table 4). It was observed that the absolute increase in temperature was higher for the T_{min} as compared to the T_{max} in both annual and seasonal time scales. Based on seasonal mean, the increase in T_{max} was 0.32ºC and 0.31ºC in the MAM and OND seasons respectively while the T_{min} recorded an absolute increase of 0.81ºC and 0.93ºC for the MAM and OND seasons respectively (1983 to 2014). These results depict similar findings by Aduma *et al.*, (2018) which established that a higher increase in absolute minimum temperature compared to maximum temperatures in Amboseli ecosystem (1960 to 2014).

4.3.2 Annual-monthly temperature variation

Analysis of average monthly temperature was done to show monthly temperature variation for both T_{max} and T_{min} in the study area in the period of thirty-one years (1983-2014). Results showed that both the average T_{max} and T_{min} monthly temperatures variations depicted a bimodal pattern as shown in Figure 10(a) and 10(b) respectively. The highest average monthly T_{max} were recorded in the months of January, February, March, September and October and were low in June, July and August. On the other hand, the average monthly T_{min} were highest in the months of March, April, May, October, November and December and lowest in June, July, August and September. It is noted that average monthly T_{max} is at the peak in February and September which are the months just before the onset of the MAM and OND rainfall seasons respectively.

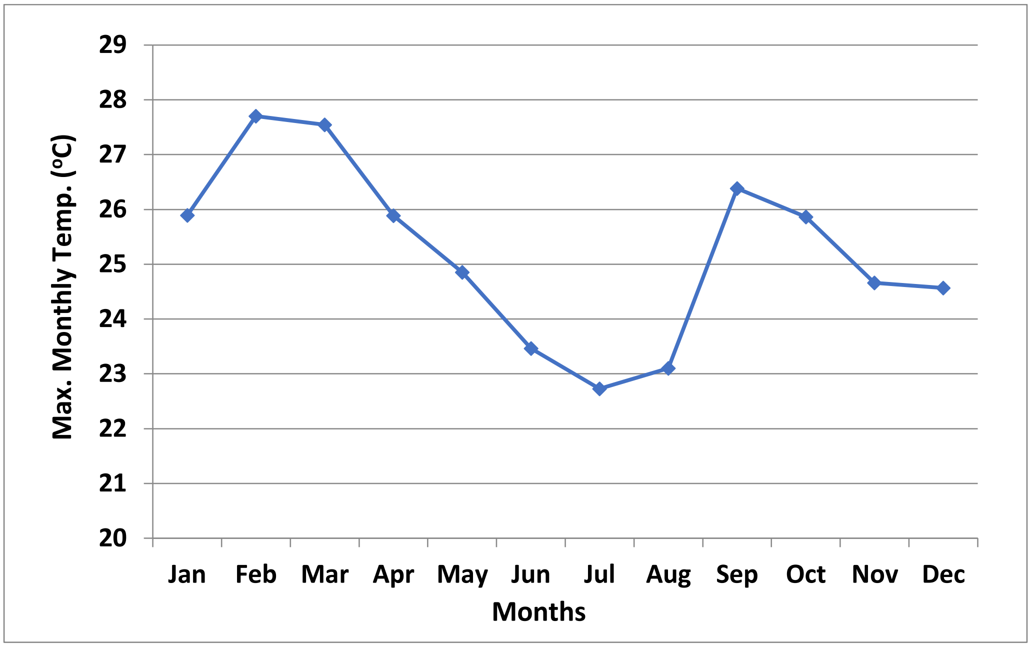


Figure 10(a): Mean monthly variation of maximum temperature in (1983-2014)

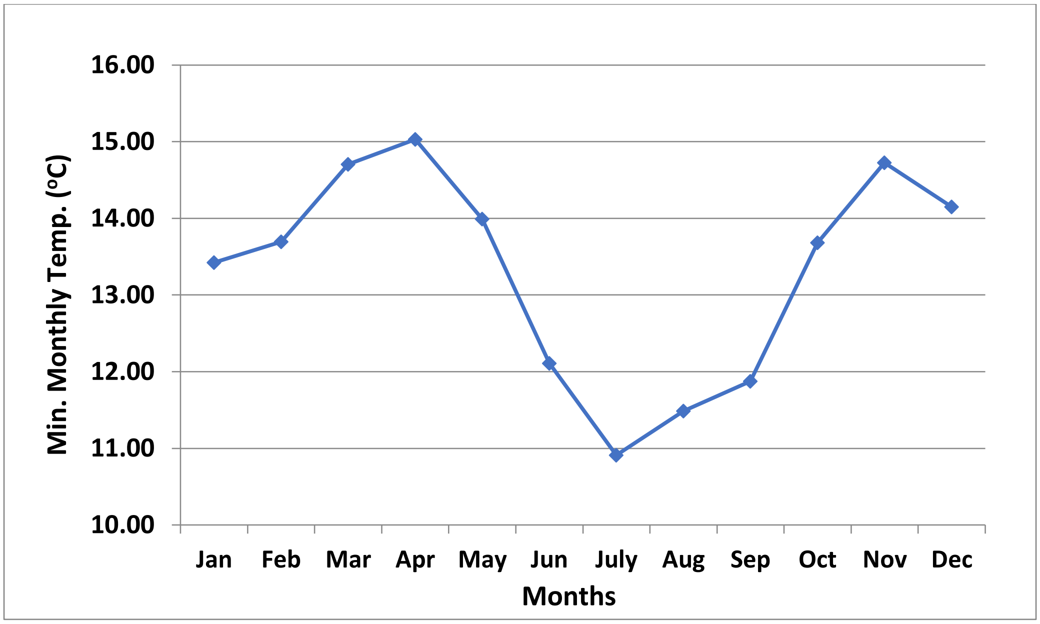


Figure 10(b): Mean monthly variation of minimum temperature (1983-2014)

4.4 Trend Analysis using Mann-Kendall Test

This section shows the significance of monthly, seasonal and annual rainfall and temperature trends as determined using the MK test.

4.4.1 Rainfall Trend Analysis

On running the MK test on monthly rainfall data, results in Table 5 were obtained.

Table 5: Mann-Kendall test for monthly rainfall

Months	**Mann- Kendall's test (Ho: there is no trend)**				
	Mann-Kendall's (S)	**Var. (S)**	**Kendall's tau**	**p-value**	**A**
January	-20.00	3458.00	-0.04	0.75	0.05
February	54.00	3417.00	0.12	0.37	0.05
March	87.00	3461.67	0.19	0.14	0.05
April	7.00	3461.67	0.02	0.92	0.05
May	16.00	3460.67	0.03	0.80	0.05
June	-16.00	3444.00	-0.04	0.80	0.05
July	2.00	3415.33	0.00	0.99	0.05
August	-29.00	3457.00	-0.06	0.63	0.05
September	85.00	3414.33	0.19	0.15	0.05
October	17.00	3416.67	0.04	0.79	0.05
November	23.00	3461.67	0.05	0.71	0.05
December	-21.00	3461.67	-0.05	0.73	0.05

Results from the MK test for monthly rainfall trends show that the computed P-value was greater than the significance level α (alpha) *=0.05* for all months. As such, the null hypothesis was not rejected implying that there were no statistically significant trends detected in the monthly rainfall time series data. Table 6 shows MK test results from annual and seasonal (MAM and OND) rainfall data.

Table 6: Mann-Kendall test for annual and seasonal rainfall

Time series	**No. years**	**Kendall's (S)**	**Var. (S)**	**Kendall's tau**	**p-value**	**α**
Annual	31	211	3141	0.49	0.00*	0.05
MAM	31	167	3141	0.38	0.00*	0.05
OND	31	117	3135	0.27	0.04*	0.05

It was observed that the computed P-values for the annual and seasonal rainfall were all less than the significance level α (alpha) $=0.05$ hence the null hypothesis was rejected implying that the annual and seasonal rainfall trends were statistically significant.

4.4.2 Temperature trend analysis

On running the MK test on annual and seasonal temperature data, results in Table 7 were obtained.

Table 7: Results for Mann-Kendall test for annual and seasonal temperature

Temperature	No. years	Kendall's (S)	Var. (S)	Kendall's tau	p-value	α
Annual						
Tmax	31	167	3141	0.38	0.00*	0.05
Tmin	31	211	3141	0.49	0.00*	0.05
MAM						
Tmax	31	47	3135	0.11	0.40	0.05
Tmin	31	162	3130	0.38	0.00*	0.05
OND						
Tmax	31	117	3135	0.27	0.04	0.05
Tmin	31	186	3139	0.43	0.00*	0.05

The MK test results for annual temperature (T_{max} and T_{min}) showed that the computed P-value was less than the significance level α (alpha) $=0.05$. The null hypothesis was therefore rejected implying that the trends in both annual T_{max} and T_{min} were statistically significant. The results of MK test on seasonal (MAM and OND) T_{min} showed that the computed P-value was less than the significance level α (alpha) =0.05 thus indicating presence of statistically significant trends. On the other hand, MK test on seasonal T_{max} showed that the computed P-value was greater than the significance level α (alpha) =0.05 for the T_{max} during the MAM season thus indicating absence of statistically significant trend, while for the T_{max} during the OND season, the computed P-value was less than the significance level α (alpha) =0.05 indicating presence of statistically significant trend.

Summary of findings

The first objective of this study aimed to analyze temperature and rainfall trends within the study area in order to ascertain monthly, seasonal and annual variations in temperature and rainfall in the study area over a 31-year (1983-2014) period. Results obtained show that climate variability and change is evident of in the area with changing trends in parameters of climatic variables including rainfall, minimum and maximum temperatures. Analysis of rainfall data showed that the area experiences a bimodal rainfall pattern distributed in two typical rainy periods referred to as the long rainy season occurring in the months of March, April and May (MAM) and the short rainy season occurring in the months of October, November and December (OND). There were no statistically significant trends ($P>0.05$) detected in the monthly rainfall data. On the other hand, seasonal rainfall trends for OND and MAM were statistically significant ($P<0.05$) with OND season recording slightly higher monthly average compared to the MAM season. The results showed variability in seasonal rainfall in the area with an increase in trends in the two rainy seasons. MAM season recorded a higher rate of increase in seasonal rainfall while also contributing more to annual rainfall variability as compared to the OND season. It was observed that the area experienced 18 years of above average rainfall and 14 years of below average rainfall over the analysis period. Results showed that the area has been experiencing an erratic rainfall pattern during the 32-year period though with a generally increasing trend. In addition, a year of heavy rains (above average rainfall) was usually preceded by one or two years of low rains (below average).

Analysis of temperature trends showed increasing trends for annual and monthly average T_{max} and T_{min} over the analysis period. Both the T_{max} and T_{min} increased at an annual rate of 0.02°C p.a with a variation of 16% and 31% for the T_{max} and T_{min} respectively. The average T_{max} and T_{min} monthly temperatures depicted bimodal trends with both temperatures being at the peak in February and September which are the months just before the onset of the MAM and OND rainfall seasons respectively. Statistically significant trends ($P<0.05$) were detected in both T_{max} and T_{min} annual and seasonal temperatures apart from the T_{max} trends during the MAM season which were not statistically significant ($P>0.05$).

The next chapter will explore smallholder farmers' perception of climate variability and change.

CHAPTER FIVE: SMALLHOLDER FARMERS' PERCEPTIONS ON CLIMATE VARIABILITY AND CHANGE

5.1 Introduction

This chapter illustrates output from the household survey while including the response rate obtained, reliability test results, socio-demographics and agriculture profile of the participating households. The chapter also illustrates results for the second objective of the study while triangulating farmers' responses obtained from the survey with farmers' perceptions gathered during the FGDs results. Findings on the climatic events that have been experienced in the area were also outlined.

5.2 Questionnaire response rate

Response rate is critical in any research due to the risk posed by non-responses bias. Non-response bias is the error which results from discrete disparity between the responses obtained in a survey versus those the non-responses. Response rate is thus useful means of gauging the potential for non-response bias; thus higher the response rate obtained in a survey, the lower the risk of non-response bias. Further, in sample surveys, the response rate is an important indicator of the validity and generalization of the findings. It is expressed as the fraction of eligible survey participants that were contacted and interviewed (Abraham, 2006).

Out of the total of 400 questionnaires which were distributed, 354 questionnaires were found to be satisfactory in completeness thus the study recorded a response rate of 88.5%. Mugenda and Mugenda (2003), states that a scale of 50% gives an adequate response rate, suitable and representative enough for analysis, 60% is a good response rate while 70% and more is considered excellent. Similarly, Babbie and Mouton (2001) assert that a response rate above 70% is very good while Saunders *et* al. (2003) states that a response rate of 52% to 100% is adequate even though for organizations.

5.3 Reliability results

Kumar (2011), Mugenda & Mugenda (2003) and Saunders *et al*. (2007) define 'reliability' as the measure of accuracy or precision made by a research instrument. The authors emphasis that a research tool is reliable if it is stable, consistent, predictable and accurate. Kumar (2011) states that the greater the degree of consistency and stability of an instrument, the more its reliability. The study used the Cronbach's coefficient alpha to estimate the consistency of Likert-items included in the questionnaires; Results of reliability test of the questionnaire is shown in Table 8.

Table 8: Cronbach's coefficient of reliability

Variable	Reliability Cronbach's Alpha	Remark
Climate variability and change	0.75	Acceptable
Seasonal rainfall changes	0.87	Good
Temperature changes	0.81	Good
Occurrence of dry periods	0.79	Acceptable
Effects of climatic events	0.99	Excellent
Measures taken against climatic events	0.82	Good
Adoption of crop management practices to deal with climate change	0.74	Acceptable
Adoption of water management practices to deal with climate change	0.78	Acceptable
Adoption of soil management practices to deal with climate change	0.91	Excellent
Factors influencing inability to implement change	0.96	Excellent

Notes: "≥ 0.9 – Excellent, ≥ 0.8 – Good, ≥ 0.7 – Acceptable, ≥ 0.6 – Questionable, ≥ 0.5 – Poor, and ≤ 0.5 – Unacceptable" (George and Mallery, 2003)

All coefficients yielded greater than 0.7 and greater than 0.9 for some sections, thus the questionnaire was accepted as consistent and reliable for the study.

5.4 Socio-demographic and household characteristics

The study evaluated respondents' socio-demographic and household characteristics which included; gender, gender of the household head, age, family size (number of members living in the household) level of education, main source of household income and number of years a respondent had been living in the community. The results obtained are shown in Table 9.

5.4.1 Gender of the Respondents

Most of the respondents were women (53.7%), who were slightly higher in number than the men respondents (46.3%). This implies that the gender ratio of the respondents was almost 1:1 which was found to be satisfactorily representative. According to Kothari (2004) a gender ratio of at least 1:2 in a study is termed as representative enough. 76.6% and 23.4% of the respondents indicated that their households were headed by male and female respectively.

5.4.2 Age of the Respondents

Age of the respondent is an important characteristic in understanding their views on a particular subject being investigated as it indicates the level of maturity of the individuals and how well they are familiar with the subject matter. The study established that majority (34%) of the respondents were of the age of 25-34 years, 25% were of the age of 35-44 years while 21% were of the age of above 55 years.

5.4.3 Level of education

It was observed that 7.3% of the respondents did not have any formal education, 34.5% and 34.2% had attained primary and secondary education respectively while 18.4% and 5.6% had attained tertiary/college and university level respectively. The findings imply that literacy level in the area was above mean which means that farmers were able to synthesize information provided by extension officers and any other knowledge provider. According to (Lutz *et al*., 2014), education is an important component which can support individuals and communities to make informed decisions when responding to challenges caused by changing climate.

Table 9: Socio-demographic and household characteristics

Variable	Response	Percentage (%)
Gender	Male	46.3
	Female	53.7
Gender of household head	Male	76.6
	Female	23.4
Age (Years)	15-24	6
	25-34	34
	35-44	25
	45-54	13
	>55	21
Education level	Primary school	34.5
	Secondary School	34.2
	Tertiary / College	18.4
	University	5.6
	No formal Education	7.3
Main Source of Income	Crop farming	76
	Livestock farming	5.9
	Off-farm employment	2
	Government employment	1.4
	Business	12.4
	Pension	0.6
	Government Welfare	0.9
	Other	0.9
Family Size	1-3 members	12.1
	4-6 members	37.3
	>7 members	50.6
Years lived in the community	1 – 5 years	7.3
	5 – 10 years	1.4
	10 – 15 years	13.3
	15 – 20 years	13.8
	20 – 25 years	16.1
	25 – 30 years	11.6
	>30 years	36.4

Source: Author's Survey, 2016

5.4.4 Period of stay in the community

Majority (36.4%) of the respondents had lived within the locality for more than 30 years; with the smallest percentage (1.4%) indicating that they had lived within the locality for a period of 5-10 years. The number of years an individual has lived in a certain locality or community is critical especially in studies with smallholder farmers since farming experience is accumulated over years. It is expected that experienced farmers have rich knowledge of the changes experienced in their local climate over time and what changes they have integrated into their farming practices to adjust to experienced changes. The fact that majority respondents had lived in the study area for over thirty years built confidence on validity of information obtained in view of farmers' perception and their adaptation to climate variability and change. This is supported by the fact that a 30-year period is considered sufficient to filter out any interannual variations or anomalies in temperature and rainfall as well study how climate variables have influenced crop yield (IPCC, 2007a).

Hypothetically, the number of years an individual has lived in a locality may be dependent on the age of the individual. However, this may not necessarily be the case since some people may have migrated into the area at an older age, or may have been born within the area but migrated to live elsewhere before coming back. Table 10 shows the Chi Square test for independence results based on the null hypothesis that, "there is no relationship between the number of years lived in the area is and the age of the respondent".

Table 10: Chi-Square Test for independence – number of years lived in an area versus age

	Value	df	Sig.
Pearson Chi-Square	196.92	24	.00
Likelihood Ratio	218.78	24	.00
N of Valid Cases	354		

**Significance level, α = 5%*

Since the P-values (Sig) are both less than the significance level of 0.05 (approximately zero), the null hypothesis is rejected. This implies that the number of years lived in the area is dependent on the age of an individual.

5.4.5 Number of members living in a household

It was observed that majority (50.6%) households reported to have a family size of 7 members and above. Although bigger family sizes are said to be a factor leading to aggravated poverty, large family sizes serve as a useful asset in providing farm labour especially for some farm management practices like soil water conservation practices hence can be an important factor towards minimizing households' vulnerability to risks posed by changing climate (Asfaw *et al*., 2012).

5.4.6 Main source of household income

Results obtained showed that majority of the households relied on crop farming (76%) as their main source of income followed by business (12.4%). On the other hand, livestock farming was third (5.9%) while government welfare and pension scored the least with 0.9% and 0.6% respectively. The fact that crop farming emerged as the main source of household income, this implies that majority of households in the locality are prone to climate changes.

5.5 Agricultural profile

The agriculture profile of the households was analyzed to establish the major crops grown, the mode of farming practiced (rainfed, irrigated or both), establish if the farmers' yields had increased or decreased and what was farmers opinion on the change in crop yield.

5.5.1 Type of farming

Majority (77.4%) of the farmers practiced rain-fed agriculture with a minor (17.51%) percentage indicating that they integrated both rainfed and irrigated farming while the smallest percentage (3.95%) stated that they practicing only irrigated farming (Table 11). The fact that most households relied on rainfed agriculture indicates the degree of vulnerability of farming systems posed by the impacts of changes in climate including low crop yield and reduced availability of irrigation water.

Table 11: Type of crop farming practiced in the area

Type of crop farming	Frequency	Percent
Rainfed crop farming	274	77.40%
Irrigated crop farming	14	3.95%
Rainfed & Irrigated crop farming	62	17.51%
None	4	1.13%
Total	354	100%

5.5.2 Types of crops grown

Maize was the major (94.92%) crop grown in the area followed by beans (66.38%), cowpeas (64.12%), pigeon peas (47.74%) and greengrams (28.53%). Minor crops grown included millet (12.15%), sorghum (5.37%), sweet potatoes (8.47%), dolichos (5.08%) and cassava (0.85%)

(Figure 11). Based on the crops grown in the area it is imperative to state that the farmers are somewhat growing some crops which can resist drought like cowpeas, pigeon peas and greengrams but it is also clear that the farmers have neglected the traditional crops termed as 'orphaned crops' like cassava and sorghum which have a significant potential to build their' resilience due to their ability to withstand harsh weather conditions and which in their processed form can also make maize flour dishes.

The fact that maize and beans were on top of the list of crops grown in the area confirms findings from the literature which have indicated that cereals serve as primary source of food and nutrition for most of the households in ASALs of lower Eastern Kenya (Omoyo *et al*., 2015; Parry *et al*. 2004). The fact that beans and cowpeas gave a high rate of production explains the compatibility of maize and beans or cowpeas in making a common delicacy for the locals referred to as '*Githeri and Muthokoi'.* Additionally, maize is easy to process and cook and can be ground to flour for making porridge or *Ugali* for which beans or cowpeas are used as an accompanying stew, readily digestible and is cheaper compared to other cereals (Omoyo *et al*., (2015).

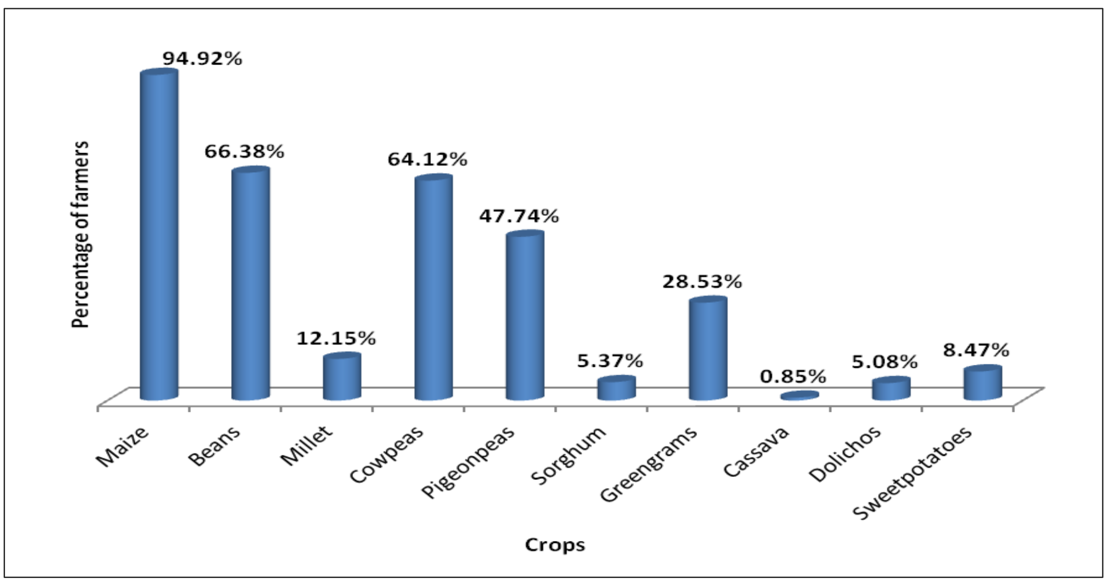


Figure 11: Types of crops grown

A Chi-Square test was done to determine the null hypothesis; "There is no relationship between growing of legumes and maize" (Table 12)

Table 12: Growing of maize versus growing of legumes (Chi-Square Test for independence)

Legume	Pearson Chi square		Likelihood ratio	
	Statistic	Sig.	Statistic	Sig.
Beans	21.24	0.00	19.70	0.00*
Cowpeas	9.35	0.00	8.90	0.00*
Pigeon peas	6.48	0.01	7.07	0.01*
Greengrams	0.37	0.55	0.35	0.55

* *Significance level, α = 5%*

The significance values (Sig.) for all legumes (beans, cowpeas and pigeon peas) except greengrams are all less than the significance level (0.05), with beans having the lowest (0.00). Additionally, for the 3 legumes the computed statistics are all greater than the critical statistic from the Chi square distribution table at 5% significance level and 1 degree of freedom; 3.84. Thus, the null hypothesis is rejected for the 3 legumes implying that growing of any of these legumes is dependent on whether the farmer grows maize, with beans being the most dependent legume on maize. For greengrams, the test statistics are greater than the critical statistic and the significance values are much greater than the significance level thus accepting the null hypothesis and thus concluding that growing of greengrams is not dependent on farmer growing maize.

5.5.3 Farmers' perception on crop yield trends

For a population that is highly dependent on crop farming as the main source of livelihood, variations in crop harvests are of great concern and would be noticed very quickly when they occur. An analysis on farmers' perception of crop yield trends over the last 5 years showed that 53.4% of the respondents had noted an increase in their crop yields while 46.6% indicated that their crop yield had not increased over the same period. The respondents attributed increase crop yield to several factors with major ones including; early planting (64.55%), use of farm-yard manure (53.97%), use of farm inputs (51.32%), use of certified seeds (50.26%) and use of drought tolerant varieties (30.69%) while minor factors included; monocropping (17.46%), conservation agriculture (13.23%), zai pits (2.65%) and favorable weather conditions (1.06%). Figure 12 shows factors leading to increase/decrease in crop yield.

On the other hand, decrease in crop yield over the last five years was attributed to several factors with major factor rated as unfavorable weather conditions (85.45%) rating followed by pests' outbreak (81.21%), inaccessibility to agricultural inputs (63.03%), decrease in soil fertility (46.67%) and inability to grow crops previously grown (6.06%). The fact that unfavorable weather conditions emerged top in the list of factors leading to decreased crop yield could imply that farmers had noted effects of unreliable, unpredictable and changing rainfall patterns since rainfall is a major weather parameter influencing crop yield.

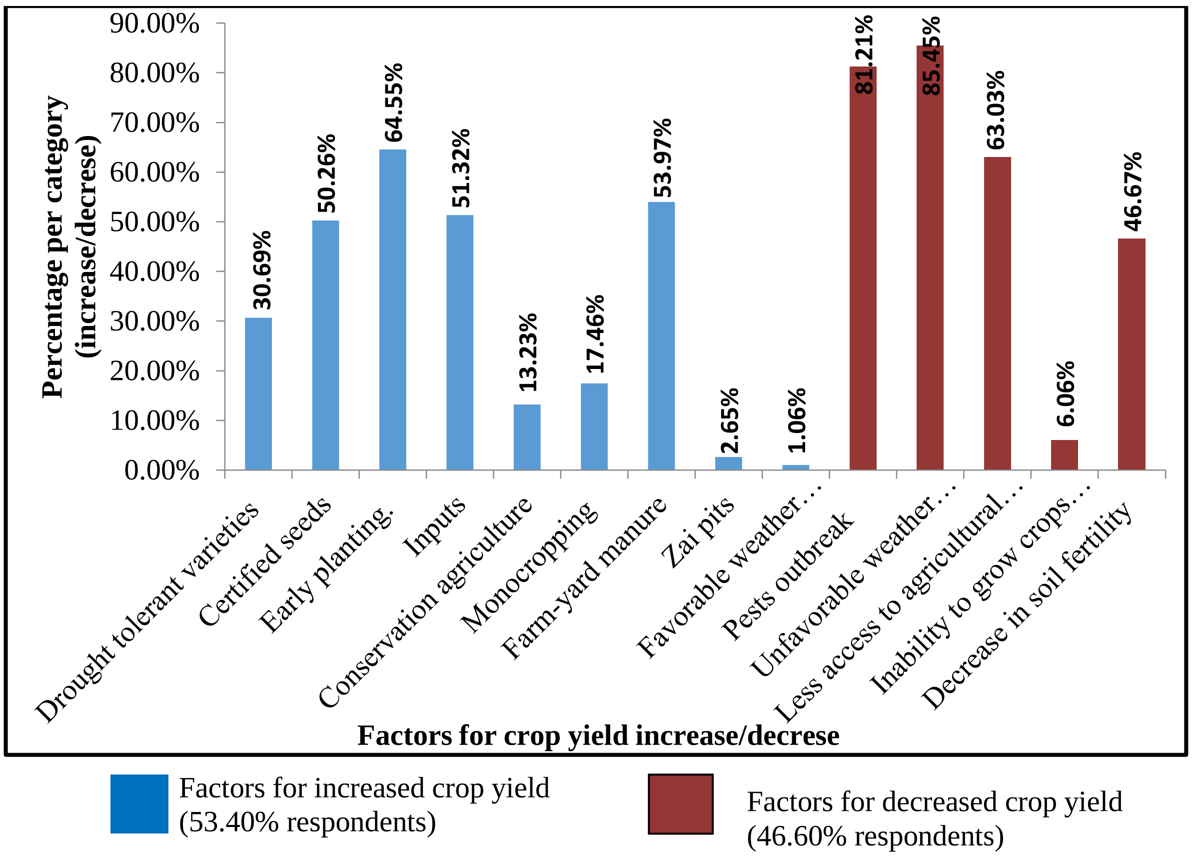


Figure 12: Factors for crop yield increase/decrease over past five years

5.5.4 Use of soil amendments

Analysis was done to determine to what extent farmers' were using soil amendments. Results showed that 77.4% of the respondents used fertilizer while 22.6% indicated that they had not used any fertilizer in the last two years. When asked what type of fertilizer they used, results showed that inorganic/chemical fertilizers and animal/farm yard manure (FYM) dominated with equal proportions of 46%, with only 6% and 2% indicating that they used compost manure and organic manure respectively (Figure 13).

It is noted that majority of the respondents are using farm yard manure and chemical fertilizers while a minority of the respondents have not embraced use of compost and organic manure which are sustainable farming systems with ability to enhance and sequester soil organic carbon and improve soil structure and fertility. The reason why majority farmers are using FYM manure and inorganic fertilizer could be that these are readily available, the farmers may be lacking technical knowhow on compost generation and organic fertilizers are still at their infant stage of introduction into the Kenyan market and there is also a perception that inorganic fertilizers offer a quicker output to increased yield compared to compost, FYM and organic manure.

A comparative study done on efficiency of chemical fertilizer versus organic manure showed that long-term additions of organic manure had the most beneficial results to crop yield and soil quality (Vermeulen *et al.*, 2012). It is imperative to note that most of the nitrous oxide (N_2O) emissions emanate from the breakdown of inorganic fertilizers as well livestock manure. It is thus critical to build capacity of farmers through practical learning approaches which would enable them realize benefits accrued hence will reduce use of inorganic fertilizers or enhance use of appropriate fertilizer application rates as well as better management of FYM.

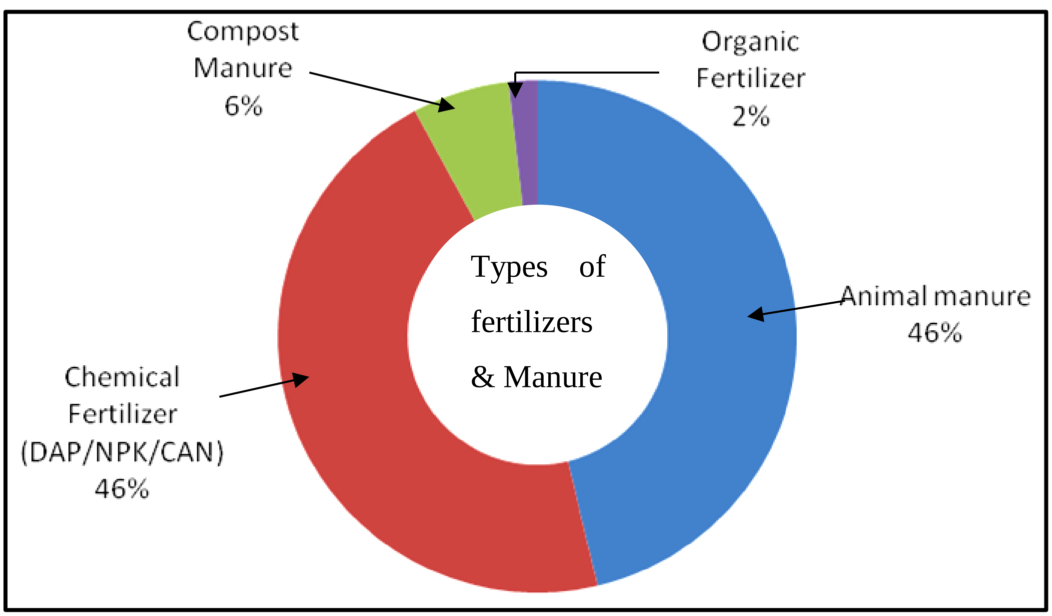


Figure 13: Variation in types of soil amendments used

5.6 Farmers' perceptions of climate variability and change in the study area

5.6.1 Farmers' perception of climate change indicators

To determine perceptions of farmers' to climate variability and change, the study evaluated farmers' perception of several climate change indicators which included; trends of seasonal rainfall, rainfall timings and patterns, drought and pest incidences, and status of food insecurity and seasonal rivers (Table 13). Majority (96.30%) respondents indicated that they had noted changes in climate in the locality in the past 10 years, 2.30% indicated they had not noted any changes in climate while 1.40% were not certain if there were any changes in the climate. The fact that majority respondents had noted climate changes in the area provides evidence that significant climatic changes in the area had happened over time.

Table 13: Farmers' perceptions of climate variability and change indicators

Variables indicators	S D	D	N S	A	S A	Mean	Mode
Trends of seasonal rainfall decreased	3.67	7.06	11.58	55.65	22.03	3.85	4
Rainfall timings have changed	1.13	7.91	9.32	50.00	31.64	4.03	4
Incidences of drought have increased	2.82	6.21	7.34	53.67	29.94	4.16	4
Food insecurity has increased	4.80	6.78	8.76	40.40	39.27	4.03	4
Rainfall patterns have become	4.24	4.80	9.04	56.50	25.42	3.94	4
Seasonal rivers have disappeared	7.34	16.10	15.54	31.64	29.38	3.60	4
Pest incidences have increased	2.54	5.08	12.15	25.99	54.24	4.24	5

Notes: SD=Strongly Disagree, D=Disagree, NS=Not Sure, A=Agree, SA=Strongly Agree
Values are expressed as Percentage (%)

Source: Authors' Survey, 2016

The findings show that majority (77.68%) of the respondents were in agreement that trends of seasonal rainfall in the area had decreased over the years. The findings concur with other findings which show that a decrease in seasonal rainfall has been noted in the ASALs of Kenya (Gichangi *et al*., 2015). According to (ROK, 2012; Cross *et al*., 2011), a decline in seasonal rainfall and rise in average temperature is an underlying cause to the increased intensity and frequency of droughts in the ASALs. The survey results support this argument since majority (93.61%) of the respondents also indicated that there was an increase in drought incidences in the area. Additionally, Funk *et al*. (2010), states that impacts of drought in East Africa appear to have become more frequent and severe in the recent years. The increase in droughts means decreased amounts of rainfall for extended periods of time which poses a serious threat to agricultural productivity hence leading to food shortage and increased malnutrition levels. Consequently, majority (79.67%) of the respondents indicated that they had experienced food insecurity. The high rate of increased food insecurity in the area is in support of majority respondents who indicated that there was a decrease in seasonal rainfall trends and increased incidences of drought which shows that rainfall trends and drought incidences are highly correlated with crop productivity.

Another outcome associated with a decrease in seasonal rainfall is drying of seasonal rivers which depend on rainfall runoff as their source of water. Drying of seasonal rivers implies water shortage for both human and animals. The survey results indicate that majority (61.02%) of the respondents stated that seasonal rivers had disappeared in the area over time which supports the relationship between decreased seasonal rainfall and drying of rivers. Findings obtained from the FGDs were also in agreement with the survey findings. One of the discussants was quoted saying:
"*Long ago whenever it rained, rivers used to fill and overflow which doesn't happen nowadays, in most cases the rainfall is scarcely enough to bring enough crop harvests…, rains are no longer reliable and have become shorter than before."* Female discussant, Ndalani.

Proper timing and prediction to know when rainfall will arrive is critical especially for smallholder farmers who depend on rainfed agriculture for their livelihood. The timing and ability to predict onset of rainfall helps farmers in proper planning on when they should prepare their land also when they need to plant. It is in this context that this aimed at establishing if farmers had noted any variations in rainfall timings. Majority (81.64%) of the respondents indicated that rainfall timings in the area had changed over time. In addition, majority (81.92%) respondents also stated that predictability of rainfall patterns had become quite difficult. The survey findings were also confirmed by farmers' statements during the FGD discussions in which the following statement was quoted:

‘*Before we had this rain in mid-February which was known as ‘Mauna indo’ because it boosted emergence of green grass for livestock…then rains would come in the first week of March, we plant, and it rained up to May and we harvested in June and July and we used to get plenty of harvest, nowadays the MAM rains come in late March or towards end of March, sometimes even in April and our crops produce less.*’ Male discussant, Iviani.

*‘In the 1980s, there were two rains which occurred in the month of September which were known as ‘Ndetua makonde’ and ‘Ngelukya miti’…it used to rains in early October when we could plant and by Jamhuri day our beans used to be read*y.’ Female discussant, Wakanesa.

During the FGDs, farmers indicated that some of the indigenous/traditional indicators which they used 20 years ago to predict onset of rainfall had become extinct. Some of the indicators which farmers indicated that had become extinct include snowing on mountains, clearing of mountain peaks, use of traditional forecasters, movement of bees, appearance of dark clouds in the sky and lightning and thunder. (A detailed description of a list of indigenous indicators which were used before in comparison to those that still farmers rely on is shown in Appendix 3. Another indicator which was used to determine farmers’ perception on climate variability and change was occurrence of pest incidences. Research has indicated that incidences and severity of some pests and diseases has been projected to increase under a changing climate. One of the reasons quoted is that pests are likely to thrive well under changing climate especially under increasing temperatures which favor insect carriers of many disease pathogens hence increasing pests’ survival (Ladányi, 2010).

This study sought to examine farmers’ perceptions on whether there had been an increase in pest incidences or not. Results showed that majority (80.23%) farmers supported that pest incidences had increased with only 7.62% indicating that pest incidences had decreased while 12.15% were not sure. The fact that majority farmers had noted an increase in pest incidences is an indication that there was a driving force behind the experienced changes hence based on literature; this could possibly point out to climate change besides other factors. The survey results were confirmed during FGDs, farmers indicated that there were many pests that had emerged which were never experienced before. Some of the pests mentioned included; Blight (maize, greengrams, cowpeas), Powderly mildew (cowpeas, sorghum), Rust (cowpeas), aphids (cowpeas, greengrams), whiteflies (pigeon peas), Bacterial wilt (cowpeas), fruitfly (Mango), *Tuta absoluta* (Tomatoes), Large grain borer (maize). The farmers indicated that the increased pest incidences had negatively impacted their farming due to loss of crop yield, loss of markets and increased cost of production since they head to rely on pesticides to manage the pests.

5.6.2 Farmers' Perceptions to changes in Seasonal rainfall

Rainfall intensity and duration as well as rainfall onset and cessation were used to determine farmers' perception of changes in seasonal rainfall. Rainfall duration is the length of time that rainfall occurs. A high intensity rainfall occurring for a short duration may affect crop growth but it does not likely have much effect on soil erosion and runoff. On the other hand, increased rainfall intensity for prolonged period of time can significantly affect soil-water processes leading to infiltration, runoff, and soil erosion. Majority (79.66%) of the respondents agreed that duration of short rains (OND) had decreased and majority (51.13%) of the respondents reported that intensity of rainfall during OND season had not increased (Table 14). These responses confirm findings from literature which have shown that in the ASALs there is a reduction in the average number of rainy days during the short rains, with the rainfall becoming more intense and the rains occurring within a very short period of time (Warner *et al*., 2015).

During the FGD discussions, it emerged that farmers' opinions were in coherence with the survey findings and also literature as captured in the following quotes:
"*These days rains are no longer reliable and have become shorter than before, in the 1980s we could rely on both rains for successful cropping, in the 1990s the OND rains became more reliable than MAM rains but as it is now we are not sure which rains we can rely on*." Female discussant, Kwa Kathule Village.

Majority (62.71%) of the respondents agreed that duration of long rains (MAM) had decreased with majority (48.59%) confirming that intensity of rainfall during MAM had increased. These results support findings from the literature which have indicated that long rains in the Eastern part of Kenya have become more erratic and on average significantly reduced (Warner *et al*., 2015). The findings further state that 'the long rains are sometimes insufficient to barely support a reliable crop harvest or even livestock rearing.' This was also in agreement with farmers' sentiments during FGD discussions, as captured below:

‘*In the 1970s and 1980s, we used to experience the MAM rains for a very long period, the rains mostly started during the first week of March upto end of May… Nowadays, the MAM rains ‘mbua ya uua’ rains too much (very intense) and lasts only for a month and then it disappears… we have nicknamed it ‘Kuluta” since it is so intense and sweeps over anything it finds on the ground including carrying away our soils and our crops don’t produce much….”* Male discussant, Kivoyo kya Senda.

The above results demonstrate that increase in rainfall intensity was experienced more during the MAM rains as opposed to the OND rains. These findings concur with IPCC (2007b) findings which showed an increase in frequency of heavy rainfall events over the years with an increase in severe consequences including floods, decrease crop yield, increased pest and disease outbreaks, rampant soil erosion and water logging.

Table 14: Farmers’ perception to changes in seasonal rainfall

Variable indicators	S D	D	N S	A	S A	Mean	Mode
Duration of short rains (OND) has decreased	7.06	7.06	6.21	62.15	17.51	3.76	4
Duration of long rains (MAM) has decreased	9.60	16.95	10.73	46.89	15.82	3.42	4
Duration of short rains (OND) has increased	16.95	46.61	19.21	13.28	3.95	2.41	2
Duration of long rains (MAM) has increased	14.41	38.42	12.99	25.42	8.76	2.76	2
Intensity of MAM rainfall has increased	10.17	20.90	20.34	29.10	19.49	3.27	4
Intensity of OND rainfall has increased	12.43	38.70	20.62	20.62	7.63	2.72	2
Onset of seasonal rainfall has become unpredictable	2.82	5.93	13.84	50.28	27.12	3.93	4
Cessation of seasonal rainfall has become unpredictable	1.41	5.93	23.16	42.37	27.12	4	4
Increased occurrence of untimely rainfall	9.04	29.66	28.81	23.45	9.04	2.94	2

Notes: SD=Strongly Disagree, D=Disagree, NS=Not Sure, A=Agree, SA=Strongly Agree
Values are expressed as Percentage (%)

Source: Authors’ Survey, 2016

It was observed that duration for both short and long rains in the area had decreased as confirmed by 79.66% and 62.71% of the respondents respectively. These proportions were associated with means greater than 3 and modes of 4 which was a confirmation that majority of the respondents were in agreement to these statements. Additionally, majority of the respondents 63.56% and

52.83% disagreed that durations of short (OND) and long (MAM) rains had increased (Table 14). With reduced rainfall durations, it was also observed that the intensity of the rainfall received had decreased, where majority of the respondents either disagreed or were not sure about the statement that intensity of rainfall had increased.

The onset and cessation of seasonal rainfall are critical determinants for successful crop performance (Omoyo *et al*., 2015). Mugalavai *et al*., 2008 asserts that "sustainable crop yield may experience significant variation depending on whether a growing season will experience a late onset or early cessation of season rainfall hence it is very critical to effectively estimate the actual start of the season." The authors further state that "it is imperative to have reliable possibility levels of onset dates of the rainy period and length of growing season are crucial for effective planning in rainfed agriculture systems." On the background of this study, majority of the respondents (69.49% and 77.40%) agreed that cessation of seasonal rainfall as well as its onset had become quite unpredictable. This could imply that farmers had noted a delayed onset and early cessation of seasonal rainfall which is an indication that getting a sustainable crop harvest in the area was at stake. According to Conway and Schipper (2011) and Aberra (2012), delay or shifts in the onset and/or cessation of seasonal rainfall has resulted to high variability of seasonal rainfall which is a cause for increased climate risks in Kenya. One of the highlights that came out during one of the FGD discussions in regard to rainfall onset was as stated below:

'*The onset of OND rains has shifted from October to November….nowadays the MAM rains come in the month of April and lasts within a very short time hence it has been difficult for us to plan when and what to plant.*' Female discussant, Mukameni.

5.6.3 Farmers' perception to changes in temperature

Majority (78.81%) farmers reported that there was an increase in daytime temperatures over the last five years with majority (65.26%) also stating that number of hot days had increased over the period (Table 15). On the other hand, 31.63% of the respondents indicated that the number of cold days had increased while 50% indicated that there was a decrease in the number of cold days over the five years while (31.36%) of the respondents were not sure whether there the number of cold days had decreased. These findings concur with results from trend analysis results in section 4.3

which showed an upward trend for both annual and seasonal T_{max} and T_{min} in the area over the analysis period (1981-2014).

Table 15: Farmers' perceptions on changes in temperatures over the last 5 years

Variables indicators	S D	D	N S	A	S A	Mean	Mode
Daytime temperatures have increased	7.06	5.37	8.76	46.89	31.92	3.91	4
Daytime temperatures have decreased	33.90	34.75	18.64	7.34	5.37	2.16	2
Number of hot days has increased	5.65	15.25	13.84	42.66	22.60	3.61	4
Number of hot days has decreased	35.31	35.03	12.71	11.58	5.37	2.17	1
Number of cold days has increased	18.64	31.36	18.36	22.03	9.60	2.73	2
Number of cold days has decreased	13.28	22.32	31.36	22.88	10.17	2.94	3

Notes: SD=Strongly Disagree, D=Disagree, NS=Not Sure, A=Agree, SA=Strongly Agree
Values are expressed as Percentage (%)

Source: Authors' Survey, 2016

The results are in agreement with IPCC (2007a) report which stated that there was an increasing deviation from the normal in trends of weather and climate events with higher T_{min} associated with more warmer and fewer cold days and nights and higher T_{max} related to warmer and increased number of hot days and nights over most land areas. Findings by Omondi *et al*., (2014) also indicate that intense temperature events such as warm days, warm nights and duration of warm spells have been noted in many parts in Kenya. Furthermore, the UNDPs climate change country profile showed that the mean annual temperature in Kenya had increased by a rate of 1^{o}C since 1960. This increase has been higher during the MAM season and has led to an increase in number of hot days and hot nights. The survey findings were verified by the FGD discussions where a farmer was quoted saying:

'*These days here is an increase and fluctuations in temperatures during periods of low temperatures, it is cold today, tomorrow it is warm, in the early 1980s "Kwai muumbi yasisivaa" 'there was dew that used to drizzle' even in dry periods of the year, this doesn't happen anymore*.'

It is thus imperative to state that smallholder farmers are likely to suffer greater impacts in their farming systems due to the noted extreme temperatures (extreme hot or cold days).

5.6.4 Farmers' Perception of Changes in Occurrence of Dry periods

Table 16: Perceptions of changes in the occurrence of dry periods over the last 5 years

Variables indicators	S D	D	N S	A	S A	Mean	Mode
Duration of dry periods has become longer	2.54	6.50	17.80	48.87	24.29	3.86	4
Duration of dry periods has become shorter	29.66	44.92	9.89	11.58	3.95	2.15	2
Frequency of dry periods has increased	7.91	13.28	18.64	40.40	19.77	3.51	4
Frequency of dry periods has decreased	31.07	39.27	14.41	10.73	4.52	2.18	2

Notes: SD=Strongly Disagree, D=Disagree, NS=Not Sure, A=Agree, SA=Strongly Agree
Values are expressed as Percentage (%)

Source: Authors' Survey, 2016

With results from table 15 showing that high temperatures and increased number of hot days had been experienced by the respondents was an indication that longer dry periods were expected. This was confirmed by the findings shown in table 16 where 73.16% and a meager 15.53% agreed to statements that durations of dry periods have increased and decreased respectively. Additionally, 60.17% indicated that frequency of dry periods had increased while 15.25% stated that frequency of dry periods had decreased. Prolonged dry spells 'termed as periods of consecutive dry days' stem out from increased rainfall variability, decrease in number of rainfall days and increased warmer temperatures. Dry spells result to reduced water levels leading to water scarcity and lack of pasture.

5.7 Climatic events and their impacts

The figure 14 shows the climatic events that were reported to occur in the area and which had significantly impacted the community in the past five years. From the results, it was evident that drought was the most (90.70%) experienced climatic event followed by crop disease (79.10%) and floods (33.30%). On the other hand, lightning, heat waves and frost were the least experienced events at 2.30%, 2.00% and 1.10% respectively.

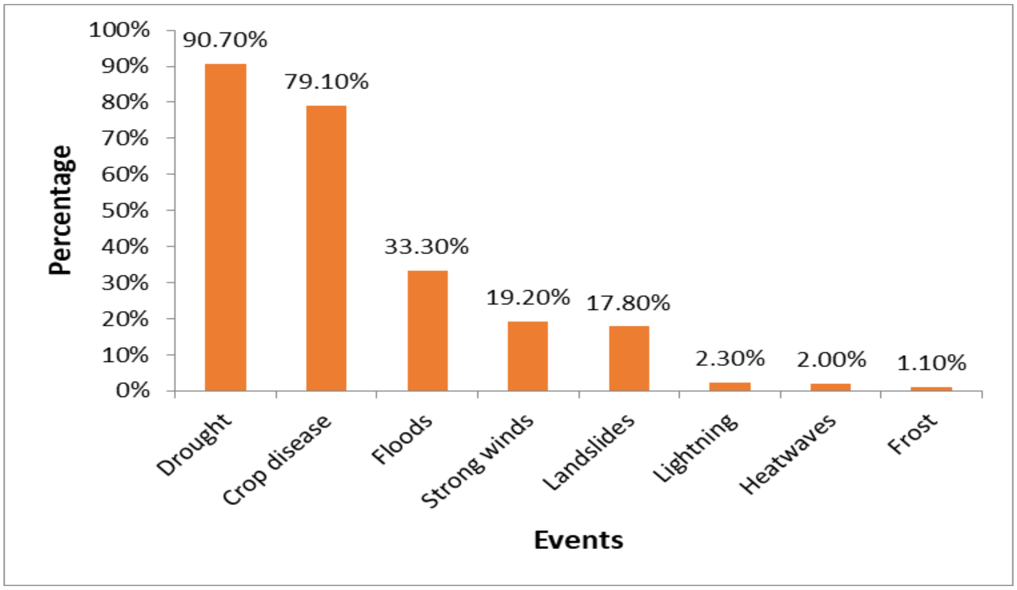


Figure 14: Experienced climatic events in the past five years

Rainfall is a key determinant in agriculture for both crop and livestock performance. The fact that drought was reported as a major climatic event experienced in the locality indicates the extent to which the area is vulnerable to climate change and variability impacts since majority of the households depended on rainfed agriculture as their major source of income. According to Funk *et al*. (2010), there exists a strong relationship between climate change and rural livelihoods especially individuals that depend on rainfed agriculture. An evaluation was done to find out the extent to which climate events had impacted the community and their livelihoods (Table 17).

Table 17: Impacts of the climatic events on communities' livelihood

Variables indicators	N A	L E	M E	LGE	V L E	Mean	Mode
Decline in crop yield	3.67	9.60	26.00	36.16	24.58	3.68	4
Loss of income	3.95	10.46	23.44	41.24	20.62	3.64	4
Loss of assets	8.76	22.59	28.53	25.14	14.97	3.15	3
Loss of entire crop	7.63	29.94	26.55	28.81	7.06	2.98	2
Decreased availability of water	6.1	9.04	22.32	28.81	33.62	3.75	5
Death of livestock	7.34	29.36	31.64	25.14	6.50	2.94	3
Decline in livestock production	4.24	7.91	24.01	48.59	15.25	3.63	4
Increase in food prices	2.82	1.98	18.93	31.92	44.35	4.13	5
Food shortage	3.67	2.54	6.50	42.37	44.92	4.22	5
Damage to infrastructure (e.g. roads, canals)	20.06	29.10	26.83	12.99	11.02	2.66	2
Notes: NA=Not at All, LE=Less Extent, ME=Moderate Extent, LGE=Great Extent, VLE=Very Large Extent Values are expressed as Percentage (%)							

Source: Authors' Survey, 2016

Results showed that majority respondents (44.35%; 44.92% and 33.62%) had experienced to a very large extent impacts from increase in food prices, food shortage and decreased availability of water respectively. On the other hand, respondents indicated that they had experienced to a large extent a decrease in crop yield (36.16%), loss of entire crop (28.81%) and loss of income (41.24%) (Table 18). The results are in agreement with results by IPCC (2011) and World Bank (2011) which indicated that there was a general reduction of potential crop yields and a decrease in water availability for agriculture in many parts of Africa. A decrease in crop yield could mean poor crop performance as opposed to the expected returns thus resulting to low yields which translates to low incomes for those depending entirely on the crop as a source of income. On the other hand, loss of an entire crop is a precursor to food shortage against market demand which translates to high food prices. A combination of these factors is a clear indication that the households' food security status is at a risk and food accessibility and availability is highly compromised by drought occurrences. Additionally, households are at a high risk to increased levels of poverty and malnutrition. Additionally, during the FGDs, farmers were able to recall some of the climate events like droughts and famine which had been experienced in the area and the impacts of the events on their livelihood (See Table 18).

Table 18: Historical climatic events and their impacts

Year	Name of the event	Cause	Impact	Intervention
2000	Yua ya Longosa*	Big drought	there was no water because both rains failed	-
1997	'Elnino'	A lot of rains	There was a lot of harvest Floods	-
1980 1981	-	Drought, depletion of maize stocks by early exports	Food shortage	NGO food for work programmes
1983 1984	'*Nikwa ngwete*'* (1 am dying with cash in my hands)	Drought, high prices	Food shortage, cattle deaths	MIDP and other terracing programmes, International aid, yellow maize imports
1960 1961	'Yua ya Mafuriko na Ndeke'* Floods and Aeroplanes	Drought followed by floods	Destroyed crops and infrastructure (roads became impassable) -Food shortage, cattle deaths (70-80% among Maasai)	£10 Million spent on food aid; air drops

*Local Name of the event

Source: Author (2016); Parry et al. (1988)

Summary of Findings

Results showed that farmers had perceived changes in local climate with majority (96.3%) of the respondents indicating that they had noted changes in climate in the past 10 years with 2.3% of the respondents indicating that they had not observed any changes in climate while 1.4% were not certain if any changes had occurred in the local climate over the past 10 years. Farmers' perception on climate variability and change variables showed some varied results in comparison to the analyzed temperature and rainfall trends although some similarities were evident for the temperature trends. Most (77.68%) of respondents stated that trends of seasonal rainfall in the area had decreased over the years which is against the analyzed rainfall trends which showed increased seasonal rainfall trends over the analysis period. Additionally, majority of the respondents stated that duration for both short (OND) and long (MAM) rains in the area had decreased as confirmed by 79.66% and 62.71% of the respondents respectively as well as majority (48.59%) confirming that intensity of rainfall during MAM had increased. These results are in agreement with analysis of rainfall trends which showed that the amount of rainfall in the study area was extremely variable though exhibiting increasing trends in the two rainy seasons with MAM season recording a higher rate of increase in seasonal levels and increased rainfall intensity as compared to OND season.

Majority of the respondents (81.64%) indicated that rainfall timings in the area had changed over time with majority respondents (69.49% and 77.40%) also indicating that cessation of seasonal rainfall as well as its onset had become quite unpredictable. This was confirmed by the analysis of the seasonal rainfall data which showed that there was increased seasonal variation as well as increased rainfall amounts especially during the MAM season.

Farmers' perceptions on temperature trends showed that majority (78.81%) respondents indicated that there was an increase in daytime temperatures over the last five years with majority (65.26%) respondents also stating that number of hot days had increased over the period. Additionally majority (50%) of the respondents indicated that the number of cold days had decreased against 31.63% of the respondents who indicated that the number of cold days had increased over a 5-year period. The farmers' perceptions on temperature trends concurred with the analyzed temperature trends which showed an upward trend for both annual and seasonal T_{max} and T_{min} in the area over the analysis period (1981-2014).

This chapter dealt with analyzing smallholder farmers' perceptions of climate parameters and indicators and relating these to analyzed meteorological data. The results demonstrated that there was a relationship between farmers' perception and analyzed climate data which indicates evidence of a changing climate in the study area.

The next chapter will examine how changes in climate variables have impacted crop production in the study area.

CHAPTER SIX: EFFECTS OF CLIMATE VARIABILITY AND CHANGE ON CROP YIELD

6.1 Introduction

This chapter presents results of the third objective of the study. The objective sought to analyze the influence of climate change variables on maize and beans yield and the relationship between the two variables for 30 years (1983-2013). The chapter also shows variation in seasonal yield for maize and beans over the analysis period (1981-2013).

6.2 Variation in Annual and Seasonal Crop Yield

Maize and beans yield over the period (1981 to 2013) was analyzed using descriptive statistics with Table 19 showing results for the annual data segregated into two periods (1981-1996 and 1997-2013), while table 20 shows results for the two cropping seasons data which is also graphically presented in Figure 15.

6.2.1 Descriptive statistics for annual crop yield

Table 19 shows the descriptive statistics for the crop yield; maize and beans for two segregated periods; 1981-1996 and 1997-2013.

Table 19: Descriptive statistics for crop yields (1981 – 2013)

Statistics	1981 – 1996		1997 - 2013	
	Maize	Beans	Maize	Beans
Mean	432	270	446	273
Median	450	270	450	270
Std. Deviation	156.63	90	235.37	161.77
Coeff. of Variation (%)	36.26	33.33	52.77	59.28

Over the period 1981 – 1996, the mean annual maize and bean yield was 432 kg/ha and 270 kg/ha respectively. The associated coefficient of variation obtained was 36.26% and 33.33% respectively indicating significant variability in crop yield for the two periods and moderate predictability. On the other hand, for the period 1997 – 2013, the mean annual maize and bean yield was 446 kg/ha and 273 kg/ha respectively. The associated coefficients of variation were relatively high at 52.77% and 59.28% for maize and beans respectively indicating higher dispersion, hence reduced predictability. The general indication is that the annual crop yield for both maize and beans was low and stable in the first analysis period, but higher though with significant fluctuations during the second analysis period.

It was therefore noted that the annual yields for maize and beans fluctuated significantly over the second analysis period.

6.2.2 Descriptive statistics for seasonal crop yield

A descriptive analysis of seasonal data for maize and beans yields for the period 1981 to 2013 yielded the statistics in Table 20 and also described by figure 15.

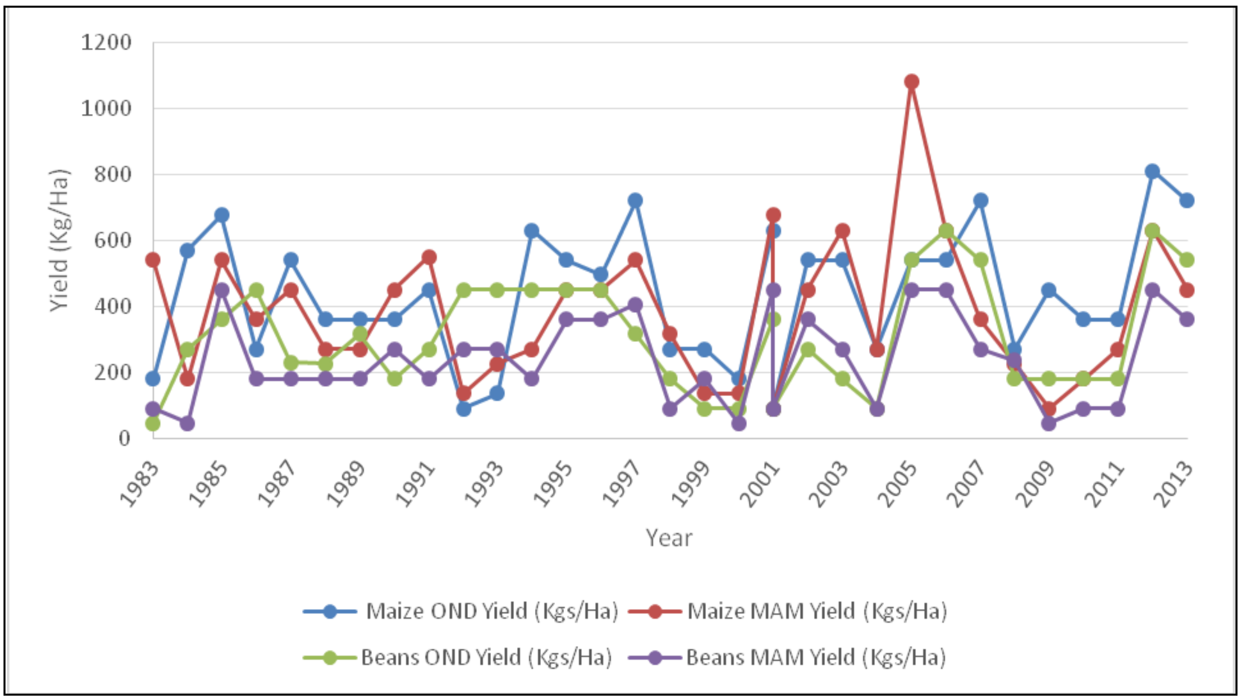


Figure 15: Seasonal variation of crop yield (1981-2013)
(*Source:* *MOALF 2016)*

The highest yields recorded for maize were 840 kg/ha and 600 kg/ha while beans recorded 531 kg/ha and 443 kg/ha as the highest yields during the OND and MAM season respectively (Figure 14). The OND season recorded seven years of yields above average as compared to the MAM season which recorded only three years of yields above the average yield for maize. In overall, the OND season recorded higher maize and beans yields than the MAM season. A comparison of crop yield trends and rainfall trends (described in chapter four) show significant direct correlation where years with lowest average seasonal rainfall depict low crop yields. For instance, low yields of beans were recorded in both cropping seasons for the year 1987 which recorded lowest amount of annual rainfall as well as lowest average seasonal rainfall.

A similar correlation is also noted for the yields of both maize and beans when they recorded a sharp decline in 1984 which also recorded lowest amount of annual rainfall, as well as lowest average seasonal rainfall (MAM and OND). Further, a similar correlation is evident in the year 2000 which recorded lowest crop yields for both maize and beans in both seasons, after recording lowest amount of annual rainfall. In most cases, it is assumed, that increase in rainfall translates to increased agricultural productivity. However, this may not always be the case especially in the ASALs where temperatures have been increasing over the years translating to increased evapotranspiration which offsets any potential increase in productivity. In particular, it has been reported that the lower Eastern region of Kenya has continued to experience high rainfall variability amidst rising temperatures that tend to increase the rate of evapotranspiration (Omoyo *et al*., 2015).

Table 20: Descriptive statistics for maize and beans yields by seasons

Crop	Lowest yields (kg/ha)	Highest yields (kg/ha)	Mean (kg/ha)	S.D(kg/ha)	CV (%)
Maize-MAM	58	600	319.44	169.67	52
Beans-MAM	32	443	255.56	103.85	40
Maize-OND	93	840	433.03	233.57	53
Beans-OND	75	531	312.34	132.90	42

It is observed that the highest mean yields for maize were recorded during the OND season (mean = 433.03 kg/ha), while the MAM season recorded a lower mean (mean = 319.44 kg/ha). Similarly, the highest mean yield for beans was recorded during the OND season (mean=312.34 kg/ha) while the MAM season recorded a slightly lower mean yield (mean = 255.56 kg/ha). However, OND season had the highest variation for both maize and beans yields with a standard deviation of 233.57 kg/ha (CV = 53 %) and 132.90 kg/ha (CV = 42 %) respectively.

Crop-yield variation is an important characteristic of agriculture which is strongly influenced by fluctuations in weather. According to Edeh *et al*. (2011), inter-annual variation in crop yield is usually associated with weather fluctuations. Rainfall is an important climate parameter for water provision towards sustainable crop productivity under rainfed agriculture hence seasonal rainfall variability greatly affects soil-water availability to crops thus posing risks to crop production (Mburu *et al.*, 2014). An analysis of rainfall variability in Yatta by Mburu *et al.* (2014), showed a steady increase in rainfall coefficient of variation indicating that variation in rainfall patterns in the area had been steadily increasing over the years which had directly impacted negatively on crop production. Other researchers have also reported that variability in climate variables is one of the major determinants of crop yield and consequently food security (Southworth *et al.*, 2000; Moriondo *et al.*, 2011).

6.3 Climate-Crop Yield relationship

The study adopted a multiple linear regression model to describe the functional climate-crop yield relationship. The structure of the model was:

$$Crop\ Yield = \beta_0 + \beta_1(Precipitation) + \beta_2(Max\ Temp) + \beta_3(Min\ Temp) + \varepsilon$$

Where ε is the random error component.

For a multiple linear regression model to be deemed statistically significant there should be no significant correlation among any two or more predictor variables in the model. A significant correlation among the variables would result to (multi)collinearity which compromises the explanatory power of the model. For this purpose, correlation analysis was conducted on all variables for each season yielding the Pearson's Product Moment correlation coefficients matrices.

6.3.1 Correlation Matrix for the MAM Season

Table 21 shows the correlation matrix illustrating correlation coefficients between the variables in the multiple linear regression model for the MAM season for the two crops; maize and beans.

Table 21: Correlation matrix for MAM season – maize and beans

	Maize	Beans	Rainfall	Max Temp	Min Temp
Maize	1.00				
Beans	0.65	1.00			
Rainfall	0.93	0.77	1.00		
Max Temp	-0.90	-0.79	-0.53	1.00	
Min Temp	-0.76	-0.72	-0.60	0.52	1.00

Correlation is said to be significant if the correlation coefficient is greater than or equal to 0.7 (i.e. $r \geq 0.7$). The results show that all predictor variables were significantly correlated with the crop yields but the variables were not significantly correlated. This implies that the variables were adequate to explain the variations in crop yield using a regression model and there was no collinearity among them.

Using least squares approach for linear regression analysis, the output in Table 22 was developed by regressing maize crop yield on the three predictors; rainfall, maximum temperature and minimum temperature for the MAM season.

Table 22: Multiple linear regression output for maize yield, MAM season

Regression Statistics					
Multiple R	0.75	Std. Error	42.55	Bp Statistic	16.93
R^2	0.56	Durbin Watson	2.01		
Adjusted R^2	0.51	Observations	30		
ANOVA					
Source	**Df**	**SS**	**MS**	**F**	**Sig.**
Regression	3	60984.53	20328.18	11.23	0.00
Residual	26	47075.47	1810.59		
Total	29	108060.00			

	Coefficients	**Std. Error**	**t Stat**	**P-value**	**VIF**
Intercept	-145.86	36.39	-4.01	0.01	
Rainfall	6.88	1.12	6.17	0.01	6.02
Max Temp	-9.61	4.07	-2.36	0.03	7.06
Min Temp	-3.38	1.58	-2.14	0.03	6.33

The regression output yielded the model;

$$Y = -145.86 + 6.88X_1 - 9.61X_2 - 3.39X_3 + \varepsilon$$

Where; Y = Maize crop yield (MAM season)

X_1 = Rainfall

X_2 = Maximum temperature

X_3 = Minimum temperature

The model showed that the amount of maize yield that was not influenced by the predictor variables was -145.86 kg/ha (the constant). This implied that without sufficient rainfall and favorable temperature, farmers would not harvest any maize from their farms but they would only incur losses in terms of fertilizers, labor and other farm inputs. Further, it was observed that a unit increase in the rainfall (X_1) resulted to 6.88 kg/ha increase in the maize yield. On the other hand, a unit increase in the T_{max} and T_{min} resulted to 9.61 kg/ha and 3.39 kg/ha decrease in maize yield respectively.

The model generated an adjusted coefficient of determination (Adjusted R^2) of 51% implying that it was not a very strong model but was statistically significant. The model (or the predictor variables captured) explained up to 51% of the variations in maize yield, while the remaining 49% of variations was due to other factors not captured in the model and pure random variations. The Durbin Watson statistic, 2.01 was very much close to 2 indicating that observations of the variables in the model were statistically independent thus indicating absence of autocorrelation/serial correlation. The F-statistic, 11.23 was greater than 2.98, the critical F-statistic obtained from the F distribution table at 5% significance level. This implies that the hypothesis of the model being statistically insignificant was rejected. This was confirmed by the P-Value (Sig) which was obtained as 0.01, much less than the significance level, 0.05.

VIF ≤ 10 indicates absence of collinearity while VIF ≥ 10 is a sign of serious multicollinearity requiring correction for the model to be usable and adequate for any prediction. It was observed that all the predictor variables were non collinear since the obtained VIFs were all less than 10. The t-statistics were all greater than 2.06, the critical t-statistic value obtained from the students' t-distribution table at 2.5% ($\alpha/2$) significance level, and the corresponding P-Values (Sig) were all less than 0.05. This implies that the hypothesis of any individual predictor being statistically insignificant was rejected.

Lastly, it was observed that the Breusch Pagan test statistic obtained was 16.93 which is less than the critical statistic value of 38.89 obtained from the Chi square distribution table. This implies that the null hypothesis of homoscedasticity fails to be rejected hence the conclusion that the regression residuals had an approximately constant variance thus being homoscedastic. All these findings led to the conclusion that the model was statistically significant in describing the relationship and adequate for prediction. Table 23 shows the regression output for bean crop yield in the MAM season.

Table 23: Multiple linear regression output for beans yield, MAM season

Regression Statistics					
Multiple R	0.78	Std. Error	39.97	Bp Statistic	18.44
R Square	0.61	Durbin Watson	1.99		
Adjusted R Square	0.57	Observations	30		
ANOVA					
Source	**Df**	**SS**	**MS**	**F**	**Sig.**
Regression	3	66314.17	22104.72	13.83	0.00
Residual	26	41543.33	1597.82		
Total	29	107857.50			

	Coefficients	**Std. Error**	**t Stat**	**P-value**	**VIF**
Intercept	143.20	59.38	2.41	0.03	
Rainfall	10.82	1.69	6.38	0.01	6.27
Max Temp	-23.19	5.45	-4.26	0.01	7.23
Min Temp	-13.27	4.69	-2.83	0.02	5.96

Source: Author, 2018

The output yielded the model;

$$Y = 143.20 + 10.82X_1 - 23.19X_2 - 13.27X_3 + \varepsilon$$

Where; Y = Bean crop yield (MAM season)

X_1 = Rainfall

X_2 = Maximum temperature

X_3 = Minimum temperature

The indication is that the amount of bean yields that are not influenced by either rainfall or temperature is 143.20 kg/ha. Further, a unit increase in rainfall results to 10.82 kg/ha increase in bean yields, while a unit increase in maximum and minimum temperatures result to 23.19 kg/ha and 13.27 kg/ha decrease in the yields. The model is associated with 57% adjusted explanatory power, indicating that it is a good model both as a functional relationship and a forecasting function.

Further, the Durbin Watson statistic, 1.99 is much close to 2 indicating absence of serial correlation. This implies that the observations used to develop the model were statistically independent. The F-statistic, 13.83 was greater than the critical F-statistic 2.98, while the P-value, 0.00 was much less than the significant level, 0.05. This implies that the model is statistically discernible. On the other hand, the VIF values are less than 10 indicating absence of collinearity, the t-statistic values are numerically greater than the critical t-statistic, 2.06, indicating that the predictors are statistically reliable and the Bp statistic is less than the critical Chi square statistic, 38.89, indicating that the residuals associated with the model are homoscedastic.

6.3.2 Correlation Matrix for the OND Season

Table 24 shows the correlation matrix for the variables in the multiple linear regression model for the OND season for the two crops; maize and beans.

Table 24: Correlation matrix for OND season – maize and beans

	Maize	Beans	Rainfall	Max Temp	Min Temp
Maize	1.00				
Beans	0.62	1.00			
Rainfall	0.92	0.82	1.00		
Max Temp	-0.86	-0.74	-0.54	1.00	
Min Temp	-0.79	-0.77	-0.49	0.64	1.00

Generally, all predictor variables are strongly related to the response variables; maize and beans crop yields. In addition, none of the predictor variables is strongly correlated to another, implying that is no collinearity or multicollinearity among the predictors. Table 25 shows the regression output for maize crop yields in the OND season.

Table 25: Multiple linear regression output for maize yield, OND season

Regression Statistics					
Multiple R	0.86	Std. Error	39.31	Bp Statistic	22.04
R^2	0.73	Durbin Watson	1.99		
Adjusted R^2	0.70	Observations	30		
ANOVA					
Source	**Df**	**SS**	**MS**	**F**	**Sig.**
Regression	3	111218.36	37072.79	23.99	0.00
Residual	26	40181.64	1545.45		
Total	29	151400.00			
	Coefficients	**Std. Error**	**t Stat**	**P-value**	**VIF**
Intercept	-141.20	24.59	-5.74	0.01	
Rainfall	6.30	0.56	11.18	0.00	4.98
Max Temp	-16.56	4.89	-3.38	0.01	5.95
Min Temp	-3.68	1.66	-2.22	0.03	7.22

The output yielded the model;

$$Y = -141.20 + 6.30X_1 - 16.56X_2 - 3.68X_3 + \varepsilon$$

Where; Y = Maize crop yield (OND season)

X_1 = Rainfall

X_2 = Maximum temperature

X_3 = Minimum temperature

It was observed that during the OND season, the level of maize yields not influenced by the three predictor variables in the model is -141.20 Kgs/Ha. Further, the maize yields increased by 6.30 Kgs/Ha for every unit increase in rainfall, decreased by 16.56 Kgs/Ha per unit increase in T_{max} and decreased by 3.68 Kgs/Ha per unit increase in T_{min}.

The adjusted coefficient of determination, 70% indicates a very high explanatory power of the model. This implies that the model and the variations in the predictor variables involved can explain 70% of the variations observed in the maize yields during this season leaving 30% as the unexplained/residual variance.

The Durbin-Watson statistic was obtained as 1.99≃ 2 indicating absence of serial correlation/autocorrelation. The computed F-statistic, 23.99, is greater than the 2.98, and the P-value, 0.00, is much less than the significance level, $\alpha = 0.05$. Further, the VIF values are less than 10 indicating absence of collinearity, the t-statistic values are absolutely greater than the critical t-statistic, 2.06, indicating that the predictors are statistically significant and the Bp statistic is less than the critical Chi square statistic, 38.89 indicating that the model is homoscedastic.

Table 26 shows the regression output for bean crop yields in the OND season.

Table 26: Multiple linear regression output for bean crop yields, OND season

Regression Statistics					
Multiple R	0.82	Std. Error	50.12	Bp Statistic	20.13
R^2	0.67	Durbin Watson	2.21		
Adjusted R^2	0.63	Observations	30		
ANOVA					
Source	**Df**	**SS**	**MS**	**F**	**Sig.**
Regression	3	133310.47	44436.82	17.69	0.00
Residual	26	65319.53	2512.29		
Total	29	198630.00			

	Coefficients	**Std. Error**	**t Stat**	**P-value**	**VIF**
Intercept	90.58	27.04	3.35	0.01	
Rainfall	7.18	0.36	19.81	0.00	6.21
Max Temp	-8.96	1.52	-5.89	0.01	5.99
Min Temp	-9.46	3.79	-2.49	0.02	6.01

The output yielded the model;

$$Y = 90.58 + 7.18X_1 - 8.96X_2 - 9.46X_3 + \varepsilon$$

Where; *Y* = Bean crop yield (OND season)

X_1 = Rainfall

X_2 = Maximum temperature

X_3 = Minimum temperature

It was observed that during the OND season, the level of bean yield that is not influenced by the three predictor variables 90.58 kg/ha. Further, the bean yield increased by 7.18 kg/ha for every unit increase in rainfall, decreased by 8.96 kg/ha per unit increase in T_{max} and decrease by 9.46 kg/ha per unit increase in the T_{min}.

The adjusted coefficient of determination, 63% indicates a high explanatory power of the model, implying that the model and the variation in the predictors can explain 63% of the variations observed in bean yields during the OND season, leaving 37% as the unexplained/residual variance. The Durbin-Watson statistic was obtained as 2.21≃ 2 indicating absence of serial correlation/autocorrelation. The computed F-statistic, 17.69 is greater than the critical F-statistic, 2.98 obtained from the F-distribution table. Also, the P-value, 0.00 is much less than the significance level, $\alpha = 0.05$. Therefore, the null hypothesis of non-significance is rejected implying that the model is statistically significant in describing the functional relationship. The VIF values are observed to be less than 10 indicating absence of collinearity, the t-statistics are greater than the critical t-statistic, 2.06, indicating that the predictors are statistically discernible and the Bp statistic is less than the critical Chi square statistic, 38.89, indicating that the error terms are homoscedastic.

Ideally a variation in temperatures, and, in most cases, extreme temperatures would result in decreased crop yields. These findings concur with the findings by Prakash (2011), which showed that increase in T_{max} had an adverse impact on maize yield in Nepal. On the other hand, the positive coefficient values obtained for rainfall implied that an increase in rainfall led to increased maize and beans yields in both seasons.

Summary of findings

A comparison of crop yield trends and rainfall trends (analysed in chapter four) showed a significant direct correlation where years which recorded lowest average seasonal rainfall depicted low crop yields. For instance, low bean yield were recorded in both cropping seasons (MAM and OND) for the year 1987 which recorded lowest amount of annual rainfall as well as lowest average seasonal rainfall. A similar correlation was also observed for both maize and beans yield which recorded a sharp decline in the year 1984 which also recorded lowest amount of annual rainfall, as well as lowest average seasonal rainfall (MAM and OND). Further, a similar correlation is evident in the year 2000 which recorded lowest crop yields for both maize and beans in both seasons, after recording lowest amount of annual rainfall.

The study used the multiple linear regression model to describe the functional climate-crop yield relationship for both crops during OND and MAM cropping seasons. Results obtained show that without sufficient rainfall and favorable temperature, farmers will have no harvest and would incur losses in terms of farm inputs (fertilizer, seed, labor and other farm inputs). Furthermore, it is observed that a unit increase in the rainfall (X_1), results to 6.88 kg/ha increase in maize yields while a unit increase in T_{max} and T_{min} resulting to 9.61 kg/ha and 3.39 kg/ha decrease in maize yield respectively. Additionally, results for the bean yield show that the level of bean yield is not influenced by the predictor variables. Furthermore, the bean yield increased by 7.18 kg/ha for every unit increase in rainfall, while bean yield decreased by 8.96 kg/ha per unit increase in T_{max} and decrease by 9.46 kg/ha per unit increase in the T_{min}.

The next chapter explored adaptation and coping strategies that farmers' had employed in their farming systems in order to cope with the experienced climatic changes. The chapter also evaluated the extent to which the adaptation and coping strategies had improved farmers' ability to deal with the experienced climatic changes.

CHAPTER SEVEN: SMALLHOLDER FARMERS' ADAPTATION STRATEGIES TO CLIMATE VARIABILITY AND CHANGE

7.1 Introduction

This chapter presents output from the household survey on sources of information that guide farmers' adaptation strategies and highlights the coping strategies that farmers' were putting in place. The chapter also illustrates results of Chi square test for independence to determine whether ability of farmers to adopt coping or adaptation strategies was dependent on gender dynamics. Finally, the chapter outlines an overview of adaptation strategies that farmers had adopted in their farming practices and extent to which the strategies had improved farmers' ability to deal with impacts of changing climate.

7.2 Sources of information on farmers' adaptation strategies

The decision by farmers to change their farming practices would be termed as viable and productive if indeed it is a well informed decision. The source and type of information disseminated to farmers to inform their choice towards adopting a change of practice in their farm as responsive measures to climate change is thus deemed critical. Figure 16 shows the sources of information that were available to the farmers on how, when and where to change their farming practices. When asked whether they had made any changes in their farming practices, 87% indicated that they had changed their practices while 13% indicated that they had not changed their practices.

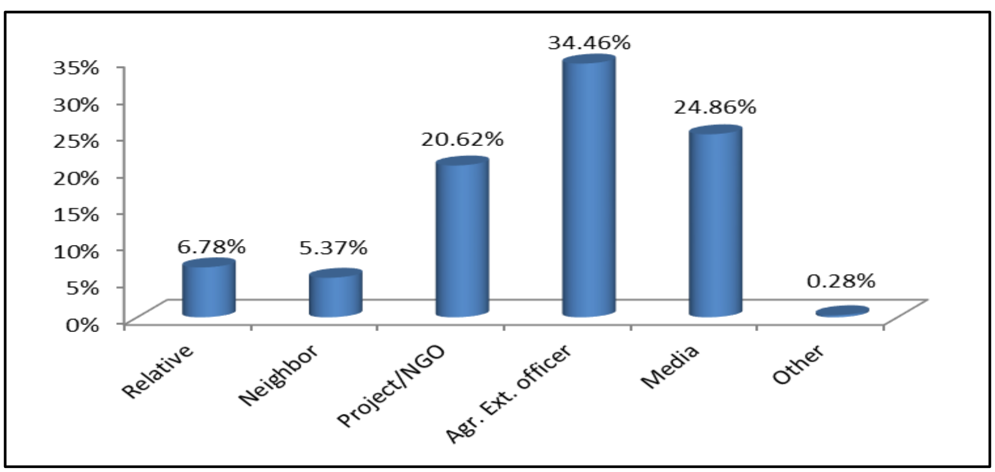


Figure 16: Source of information on climate change adaptation

Results showed that majority of the respondents received information from agricultural extension officers (34.46%), followed by media (24.86%) while project/NGO accounted for 20.62%. On the other hand, minority farmers indicated that they got information from relatives and neighbors with 6.78% and 5.37% respectively while a mere 0.28% received information from other sources. These proportions summed up to 92.37% of the respondents leaving 7.63% of respondents who may not have respondent to the question which could imply that they did not access any information towards adopting adaptation strategies in their farms. Even though extension service providers emerged as the main source of information on farmers' adoption of adaptation strategies to avert climate change, the percentage is still low which calls for the government to improve their support in information dissemination to farmers to secure their farm productivity in the face of climate change.

7.3 Farmers' coping strategies

An understanding of how households cope with risks and impacts posed by changes in climate is important towards building their resilience (FAO, 2016)**.** Coping strategies refer to social or economic activities which become options for people or communities to obtain food, income or services when their normal means of livelihood have been disrupted (WFP, 2009). The study intended to find out the extent to which a set of selected coping mechanisms had improved the households' capacity to cope with experienced climatic events. The results obtained are presented in table 27. The results showed that most households reported that selling of assets (38.70%), off-farm employment (36.16%) and reduction of household expenditure (38.70%) had improved to a large extent their ability to cope with the impacts of the experienced climatic events. The findings concur with a report by Tongruksawattana (2014) which stated that "in many poorer households, selling assets and reducing household consumption are common strategies to cope with consequences from drought, floods and pests and diseases". It has been reported that selling of household/farm assets (land, livestock, farm tools etc) is a severe form of coping practice because it is less reversible and depletes households' resources thus increasing their vulnerability (FAO, 2012; Gichangi and Gatheru, 2018). The results further showed that assistance from friends (40.96%) and reduction on household food consumption (43.50%) had improved to a moderate extent the households' ability to cope with experienced impacts of climatic events. Measures that were reported to have no influence on households' ability to cope with the experienced climatic events (not at all category) included migration to new area (78.81%), receipt of government donations/relief food (49.72%) and migration of household member (57.06%). Migration as a coping strategy could focus on movement from rural to urban areas in search of other employment opportunities hence the fact that migration didn't have any influence on the ability of households to cope with experienced climatic events could imply that most of those living in the farms were older generation.

Table 27: **Impact of selected coping measures on farmers' coping capacity**

Variables indicators	N A	L E	M E	LGE	V L E	Mean	Mode	Chi Sq. (9.49_critical χ^2)
Migrated to new area	78.81	16.38	2.54	1.41	0.85	1.29	1	2.15
Received government donations/relief food	49.72	38.42	8.19	2.82	0.85	1.67	1	2.91
Assistance from friends	12.15	37.85	40.96	7.63	1.41	2.48	3	4.40
Sold asset	6.78	7.91	31.07	38.70	15.54	3.48	4	9.16
Borrowed	6.50	25.99	26.55	25.14	15.82	3.18	3	1.84
Off-farm employment	7.06	11.30	19.49	36.16	25.99	3.63	4	5.28
H/hold member migrated	57.06	21.75	12.15	7.34	1.69	1.75	1	1.87
Reduced h/hold food consumption	12.71	22.32	43.50	19.21	2.26	2.76	1	8.62
Reduced h/hold expenditure	15.54	14.69	16.10	38.70	14.97	3.23	4	7.61

Notes: NA=Not at All, LE=Less Extent, ME=Moderate Extent, LGE=Great Extent, VLE=Very Large Extent, Values are expressed as Percentage (%)

Source: *Author's survey, 2018*

In addition to the above findings, Chi square test for independence was conducted to determine whether ability of farmers to adopt coping strategies was dependent on gender. Hypothetically, some strategies may be dominantly adopted by a given gender due to access to resources, physical stamina and socialization among other factors. Several authors have reported that there is a distinction in the way men and women perceive climate changes due to their unique and socially constructed gender responsibilities, status and identities which result to different coping strategies and responses (Lambrou and Nelson, 2010; Pettengell, 2010; Otzelberger, 2011). The computed Chi-Square statistic for each Likert item was compared with the critical Chi-Square statistic and the null hypothesis of independence rejected where the computed statistic was greater than or equal to the critical statistic. For the coping strategies, it was observed that none of the computed Chi-Square statistics was greater or equal to the critical Chi-Square statistic of 9.49. As such, the null hypothesis of independence was not rejected implying that adoption of coping strategies was independent of gender.

7.4 Farmers' Adaptation Strategies

7.4.1 Crop management strategies

Results obtained showed that practices with a rather high adoption rate were change of planting dates (48.32%), crop diversification (42.73%), use of certified seed (42.40%), planting drought tolerant crop varieties (37.61%) and early planting (35.91%). The farmers' opinion was that their ability to cope with experienced climatic changes had improved to a large extent after adopting drought tolerant crop varieties (13.28%), crop diversification (22.60%) and use of certified seed (14.41%) (Table 28). Farmers indicated that changing planting dates had improved their ability to cope with climatic changes to a moderate extent. The survey findings were in agreement with FGDs where farmers indicated that they had opted to grow more of cowpeas and greengrams as opposed to beans which they grew more in the past since they had noted that beans yields were no longer sustainable but cowpeas and greengrams were better yielding. Farmers also indicated that they had diversified their crop production to include fruits and vegetables which had proved to enhance their farm incomes. During the discussions, farmers also noted that they were planting earlier than before since they had noted that rains had become quite shorter and they considered planting certified seeds rather than their traditional seeds, a practice they had adopted from field demonstration trials set up by some of the donor projects.

On the other hand, the least adopted practices were change of crop variety (15.31%), crop rotation (18.17%), monocropping (12.42%), growing orphan crops (18.63%) and agroforestry (15.08%) (Table 29). These findings are consistent with other results which have shown that the most common crop management adaptation measures among smallholder farmers in SSA were changing planting dates, crop diversification and changing crop types (Bryan *et al*., 2013; Ofuoku, 2013). According to Bryan *et al*. (2013), one of the approaches to deal with drought is to encourage farmers to plant drought tolerant crops also referred as “orphan crops” such as cassava, millet, sorghum, cowpeas, and greengrams. However, most of these crops which were traditionally widely consumed are nowadays considered as “the poor man’s crops” which has put off some of the farmers from cultivating them. This could be the reason why the rate of adoption of growing orphan crops was slightly lower (18.6%).

On independence of adoption of crop management strategies on gender, it was observed that adoption of the crop management strategies was independent of gender except for ‘planting drought tolerant crop varieties’ and ‘growing orphan crops’ whose computed Chi-Square statistics (16.70 and 13.24 respectively) were greater than the critical Chi-Square statistic (11.07). This implies that there are underlying issues that hinder one gender from being able to adopt these strategies.

Table 28: Crop management strategies and farmers’ ability to deal with climatic changes

Variables indicators	**% adopted**	**N A**	**L E**	**M E**	**LGE**	**V L E**	**Mean**	**Mode**	**Chi Sq. (11.07)**
Change of planting dates	48.32	1.98	10.45	22.88	10.17	2.82	3.03	3	2.91
Change of crop variety	15.31	0.85	2.54	5.37	4.52	1.98	3.28	3	3.45
Planting drought tolerant varieties	37.61	1.41	5.93	12.71	13.28	3.95	3.33	4	16.70
Crop diversification	42.73	2.26	1.98	10.17	22.60	5.65	3.64	4	7.46
Use of Certified Seed	42.40	1.41	9.04	9.32	14.41	8.19	3.45	4	4.56
Crop Rotation	18.17	1.69	2.26	3.11	4.52	6.21	3.63	5	6.44
Monocropping	12.42	1.13	3.39	2.54	2.54	2.82	3.20	2	2.29
Early Planting	35.91	1.13	3.67	17.51	9.32	4.24	3.33	3	4.41
Growing Orphan Crops	18.63	2.82	3.95	4.52	4.80	2.54	3.12	4	13.24
Agroforestry	15.08	2.54	7.63	2.82	0.85	1.13	2.36	2	0.73

Notes: NA=Not at All, LE=Less Extent, ME=Moderate Extent, LGE=Great Extent, VLE=Very Large Extent; Values are expressed as Percentage (%)

Source*: Author’s survey, 2018*

7.4.2 Soil Management Strategies

Table 29 shows the adoption level as well as extent to which the soil management practices considered in this study had improved respondents' ability to cope with climate change impacts. Use of inorganic fertilizers was the most adopted soil management practice with an adoption rate of 50.78% followed by use of farm yard manure (45.48%). Farmers indicated that use of inorganic fertilizers and farm-yard manure had improved their ability to deal with climatic changes to a large and moderate extent respectively. On the other hand, all the other practices recorded a lower rate of adoption with mulching (12.15%), reforestation (12.99%), retaining crop residues (17.51%), use of organic fertilizers (19.21%), afforestation (24.29%) and CA (28.53%). The low rate of adoption of such practices which are considered as climate-smart techniques and have potential benefits in increasing crop productivity and farmers' resilience is a cause for concern and clearly shows how farmers in the area are vulnerable to impacts of climate change. Even though CA was a new technique, it had recorded a slightly higher adoption rate as compared to afforestation and use of organic fertilizers which could be attributed to the fact that the practice was under promotion by a FAO-CA project in the area by the time the survey was conducted. The low adoption rate of reforestation and afforestation concur with findings from the Machakos County integrated development plan (CIDP) which indicated that there was a low forest cover in the County. Since afforestation and reforestation are some of the proposed mitigation actions in the current CIDP, it is expected that with its implementation the adoption rate will increase thus increased climate change mitigation.

Adoption of soil management strategies was found to be independent on gender with the exception of 'reforestation' whose computed Chi-Square statistic (16.05) was found to be greater than the critical Chi-Square statistic (11.07). This may be attributed to factors such as land ownership which is mainly dominated by the male gender, in that they may have cleared forests and other vegetation cover to create farming land and will not allow their female counterparts do reforestation on the land as a climate variability response strategy. It is also notable that deforestation is labor intensive and requires physical stamina and resources which may not be available for the female farmers. Therefore since it's the males who do deforestation, they will control reforestation.

Table 29: Soil management strategies and farmers' ability to deal with climatic changes

Variables indicators	% Adopted	N A	L E	M E	LGE	VLE	Mean	Mode	Chi Sq. (11.07-Critical χ^2)
Use of CA	28.53	2.26	8.19	13.28	1.98	2.82	2.82	3	6.04
Mulching	12.15	0.85	4.24	4.52	2.26	0.28	2.74	3	2.42
Retaining crop residues	17.51	0.56	3.95	7.06	3.67	2.26	3.18	3	5.00
Use of Farm Yard Manure	45.48	1.13	6.21	15.82	15.25	7.06	3.46	3	4.88
Use of inorganic fertilizers	50.28	1.69	7.63	18.08	18.36	4.52	3.33	4	5.91
Use of organic fertilizers	19.21	1.69	3.95	4.24	5.08	4.24	3.32	4	9.00
Afforestation	24.29	1.41	13.56	3.67	3.67	1.98	2.64	2	3.03
Reforestation	1.99	2.82	3.39	4.24	0.85	1.69	2.63	3	16.05

Notes: NA=Not at All, LE=Less Extent, ME=Moderate Extent, LGE=Great Extent, VLE=Very Large Extent, Values are expressed as Percentage (%)

Source*: Author's survey, 2018*

The low adoption of most of the sustainable soil management practices indicates that there is need to sensitize farmers on benefits of proper soil management which include among others; restoration of soil fertility, increased soil-water retention capacity and reduced soil degradation. Sometimes, due to limited land, smallholder farmers engage in unsustainable land management practices such as continuous cropping, overuse of chemical fertilizers which lead to depletion of soil organic carbon (SOC), loss of natural soil fertility and soil quality leading to loss of soil productivity hence translating to low crop yield. According to Chesterman and Neely (2015), a research conducted by KALRO showed that integration of soil management approaches (use of inorganic and organic inputs) had the potential to greatly increase water retention in soils. On the other hand, inorganic fertilizer had no effects on soil moisture. Additionally, the research established that integrated soil fertility management resulted to increased sorghum yield in drier parts of Embu County. When it comes to farmers' adaptation, it is thus critical to focus on which practices farmers have considered towards restoring soil productivity for increased crop production.

7.4.3 Water management practices

Table 30 presents the rate of adoption by farmers of the various water management strategies that were evaluated and the extent to which they had improved farmers' ability to cope with climate risks. Results show that water conservation recorded the highest (62.71%) adoption rate followed by water harvesting (53.95%), then use of irrigation system (14.69%) and lastly digging well/borehole (13.56%). Majority (23.73%) of the respondents who had adopted water conservation indicated that the technique had improved to a large extent the farmers' ability to deal with climate changes with 25.42% of the adopters indicating that the technique had improved their coping capacity to a moderate extent.

On the other hand, 16.1% of the adopters indicated that water harvesting had improved their adaptive capacity to a moderate extent while 20.34% and 2.54% of the adopters indicated that water harvesting had improved their ability to cope with climatic changes to a less extent and not at all respectively. For irrigation, 2.54% and 5.65% of adopters indicated that the practice had improved their ability to cope with climatic changes to a moderate and large extent respectively. Irrigation techniques that are mostly used by smallholder farmers include watering can, water pump and drip irrigation. The reasons why irrigation recorded low adoption could be due to the fact that farmers had indicated that many rivers had dried up in the area hence there was no water available for irrigation. Another possibility could be that greater part of farmers have limited resources hence not able to afford drip irrigation and water pumps. A study conducted by Woltering *et al*. (2011) to compare drip irrigation and watering cans showed that drip irrigation achieved greater yield and better returns as compared to watering cans. The low rate of adoption of drip irrigation as an adaptation strategy could also justify the high levels of vulnerability and increasing risks posed by climate change shocks to the smallholder farming systems.

The adoption of water management strategies in addressing climate change adversities was found to be entirely independent on gender since all computed Chi-Square statistics were less than the critical Chi-Square statistic (11.07), which led to the failure to reject the null hypothesis of independence. This implies that the strategies were adopted evenly across gender. This is contrary to a study that established that adoption of water management strategies such as irrigation was more aligned to men due to cultural and socio-economic factors such as access to labor and land tenure systems (Assan *et al*., 2018).

Table 30: Water management strategies and farmers' ability to deal with climatic changes

Variables indicators	% Adopted	N A	L E	M E	LGE	VLE	Mean	Mode	Chi Sqr (11.07)
Water Harvesting	53.95	2.54	20.34	16.1	9.94	5.93	2.92	2	6.54
Water Conservation	62.71	1.13	3.67	25.42	23.73	8.76	3.56	3	3.10
Use of Irrigation System	14.69	1.98	1.98	2.54	5.65	2.54	3.33	4	2.54
Digging Well/Borehole	13.56	2.82	5.65	2.26	1.98	0.85	2.44	2	5.10

Notes: NA=Not at All, LE=Less Extent, ME=Moderate Extent, LGE=Large Extent, VLE=Very Large Extent, Values are expressed as Percentage (%)

Source*: Author's Survey, 2018*

For those respondents who had adopted digging well and boreholes, 2.26% indicated that the strategy had improved their ability to cope with climate change impacts to a large extent while 5.65% stated that the practice had to a moderate extent improved their ability to cope with climate change impacts. The reason for the minimal adoption rate for borehole and wells could be attributed to declining water table which is attributed to increasing drought owing to limited rainfall recorded in the study area. Another reason that could be attributed to the low adoption rate of the borehole could be due to the fact that technology for borehole establishment is quite expensive and also the machinery is not readily available to most of the rural households

Summary of Findings

The results show that farmers had adapted to climate change impacts using different crop management practices with high rate of adoption including; change of planting dates (48.32%), diversification of crops (42.73%), use of certified seeds (42.40%), planting drought tolerant varieties (37.61%) and early planting (35.91%). The farmers' opinion was that their ability to cope with experienced climatic changes had improved to a large extent after adopting drought tolerant crop varieties (13.28%), crop diversification (22.60%) and use of certified seed (14.41%). On the other hand, the least adopted crop management practices were change of crop variety (15.31%), crop rotation (18.17%), monocropping (12.42%), growing orphan crops (18.63%) and agroforestry (15.08%).

For soil management practices, the study established that use of inorganic fertilizers was the most adopted practice with an adoption rate of 50.78% followed by use of farm yard manure (45.48%). Consequently, farmers indicated that use of inorganic fertilizers and farm-yard manure had improved their ability to deal with climatic changes. On the other hand, all the other soil management practices recorded a lower rate of adoption with mulching (12.15%), reforestation (12.99%), retaining crop residues (17.51%), use of organic fertilizers (19.21%), afforestation (24.29%) and CA (28.53%). Adoption of soil management strategies was found to be independent on gender with the exception of 'reforestation' whose computed Chi-Square statistic (16.05) was found to be greater than the critical Chi-Square statistic (11.00).

Results on adoption of water management strategies showed that water conservation had the highest (62.71%) adoption rate followed by water harvesting (53.95%), while adoption of use of irrigation system and digging of well/boreholes recorded lower adoption rates of (14.69%) and (13.56%) respectively. Majority (23.73%) of those who had adopted water conservation indicated that the practice had improved their ability to deal with climate change to a large extent with 25.42% of the adopters indicating that the technique had improved their coping capacity to a moderate extent. On the other hand, majority (20.34%) of those who had adopted water harvesting indicated that practice had improved their ability to cope with climatic changes to a less extent while 16.1%, 9.94% and 2.54% of the adopters indicated that water harvesting had improved their ability to cope with climatic changes to a less extent large extent and not at all respectively. For irrigation, 2.54% and 5.65% of adopters indicated that the practice had improved their ability to cope with climatic changes to a moderate and large extent respectively.

In spite of findings from the previous chapter indicating that majority of farmers had perceived changes in their local climate with concurrent opinions of evidence of climate change indicators, adoption of adaptation strategies explored in this study still remains low. The need to build and enhance adaptive capacity of the smallholder farmers in the study area is thus critical with a focus to integrate and uptake CSA approaches in their farming practices.

The next chapter will address integration of selected climate-smart agriculture models in smallholder farming practices for increasing their crop productivity and resilience.

CHAPTER EIGHT: IMPACT OF CLIMATE-SMART AGRICULTURE OPTIONS ON CROP YIELD

8.1 Introduction

This chapter presents results obtained from the on-farm demonstration plots where cropping data for crops grown under the climate-smart agriculture (CSA) options in comparison with the conventional tillage (CVT) approach was obtained for three cropping seasons. The aim of the objective was to find out the viability of adopting the CSA against conventional tillage. The chapter outlines comparisons which were made on crop performance (yield) from the tested CSA approaches (CA and use of zai pits) which were each tested independently against the CVT.

8.2 Performance of maize crop in CA versus CVT Plots

Performance of maize under CA in comparison to CVT was evaluated for three cropping seasons (OND 2016; MAM 2017 and OND 2017). Figure 17 shows the mean yield (Kg/ha) of maize obtained from the treatments over the three seasons.

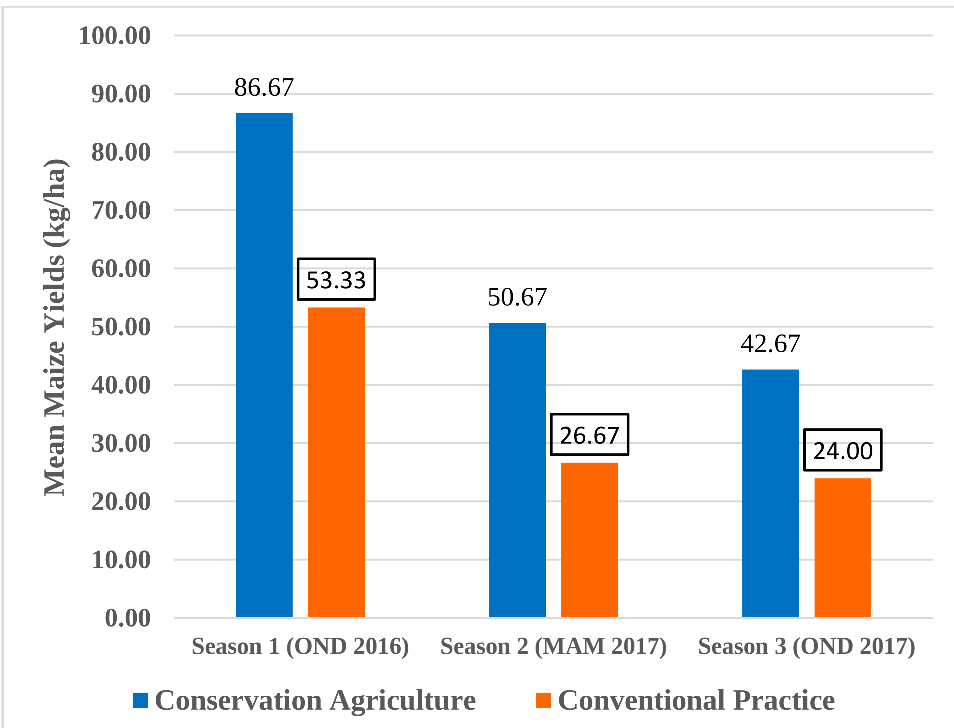


Figure 17: Mean maize yield from CA versus CVT Plots (2016/2017 Cropping seasons)

It was observed that maize performed better in the first season (OND 2016) by recording a mean yield of 86.67kg/ha as compared to the other seasons which recorded 50.67kg/ha and 42.6kg/ha respectively. Moreover, the recorded maize yield was higher under the CA method than the CVT method in all the seasons. This implies that with all other factors held constant, CA method has the potential to increase performance of maize than the CVT method. To determine whether the difference in the crop yield under the two farming methods was statistically significant, ANOVA test was conducted on the data yielding the results in Table 31.

Table 31: ANOVA for mean yield of maize (CA versus CVT)

Season	F-Statistic	P-Value	F-Critical
OND 2016	36.76	0.00*	7.71
MAM 2017	16.20	0.00*	7.71
OND 2017	5.76	0.07	7.71

* *Significance level, α = 5%*

It was observed that the Computed F-statistic for the OND 2016 and MAM 2017 were greater than the F-Critical value and the corresponding P-Values were less ($P<0.05$) than the test significance level (0.05). The null hypothesis (H_o) of equality of mean crop yield is thus rejected for the two seasons hence drawing the conclusion that the difference in the performance of maize crop under CA in comparison with CVT was statistically significant. However, for the OND 2017 season, the computed F statistic was less than the critical F-statistic and the P-value is greater than the significance level (0.05). Consequently, the null hypothesis is not rejected thus implying that the difference in the performance of maize under the CA in comparison to the CVT was not statistically significant in the OND 2017 cropping season.

8.3 Performance of greengram crop in CA versus CVT Plots

Performance of greengram under CA in comparison to CVT was evaluated for three cropping seasons (OND 2016; MAM 2017 and OND 2017). Figure 18 shows the mean yield (kg/ha) of greengram obtained from the treatments over the three seasons.

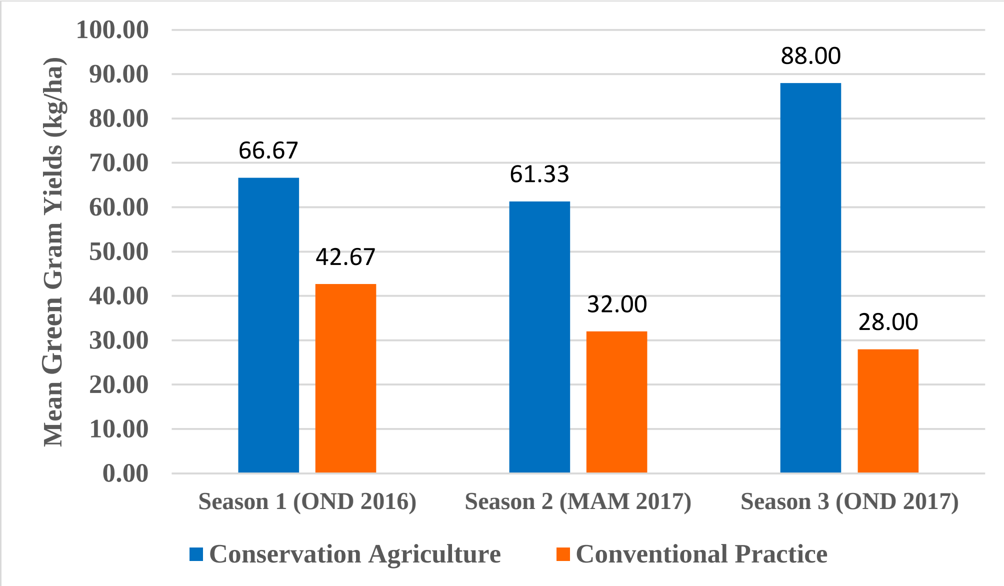


Figure 18: Greengram yield from CA versus CVT Plots (2016/2017 Cropping Seasons)

The highest yield for greengram was recorded for the CA farming system during the OND 2017 season which recorded a mean yield of 88kg/ha followed by OND 2016 (67.67kg/ha) and MAM 2017 season (61.33kg/ha) respectively. From the results, it is evident that the crop yielded higher under the CA model in comparison to the CVT approach. Table 32 shows the ANOVA results done to determine if the mean yield for greengram under the CA model and CVT were significantly different or not.

Table 32: ANOVA for mean greengram yield (CA vs CVT)

Season	F-Statistic	P-Value	F-Critical
OND 2016	23.14	0.01*	7.71
MAM 2017	5.5	0.08	7.71
OND 2017	37.5	0.00*	7.71

* *Significance level, α = 5%*

The ANOVA results showed that during the OND 2016 and OND 2017 season, higher values were obtained for the computed F-statistic as compared to the critical F-statistic value. On the other hand, P-value was less ($P<0.05$) than the significance level for the aforementioned seasons. In this regard, the null hypothesis of equality was rejected at significance level α (0.05) for these seasons, implying that the mean greengram yield obtained under CA and CVT models was significantly different, with CA recording higher yields than the CVT.

On the other hand, for the MAM 2017 season the computed F statistic was less than the critical F statistic while the P-value was greater ($P>0.05$) than the significance level. This led to the failure to reject the null hypothesis, hence the conclusion that the difference in green gram yield during this season was not statistically significant.

Other findings have also shown that CA has benefits in increasing maize yield as a water harvesting technique hence crops are able to take advantage of the increased soil moisture in places where low rainfall is experienced (Rockström *et al*., 2009). Results from CA trials in Zambia showed that there was an increase of up to 78% in maize yield after four cropping seasons in comparison to a conventional control using a ridge and furrow system (Thierfelder *et al*., 2013). These findings clearly demonstrate benefits accrued by using CA in crop production. Some of the benefits cited include addressing high water losses associated with surface runoffs through increased water infiltration and reduction of water evaporation accrued from the principle of minimum soil disturbance and protection of soil cover. Soil fertility is also enhanced in degraded soils through increased soil carbon content by use of soil cover and increase in efficiency of fertilizer through precision application (Marongwe *et al*., 2011). It is thus imperative to state that CA is a viable solution to overcome climate change impacts already experienced in the study area which were justified by farmers' responses on their perceptions of climate change. These include increasing temperatures, erratic and changing rainfall patterns, increased food insecurity and drought incidences. A wide-scale adoption of CA in the smallholder farming systems will thus provide long-term benefits towards mitigating the effects of climate change as well as enhancing farmers' resilience.

8.4 Performance of maize crop in Zai Pits versus CVT Plots

Performance of maize in zai pits model in comparison to CVT was evaluated over the three cropping seasons (OND 2016; MAM 2017 and OND 2017). Figure 19 shows the variation in the mean yield of maize under Zai Pit model and the CVT method. The results show that maize yield from the experimental plots was higher during the 2016 OND season with Zai pit model recording (78.67kg/ha) against the CVT (36kg/ha).

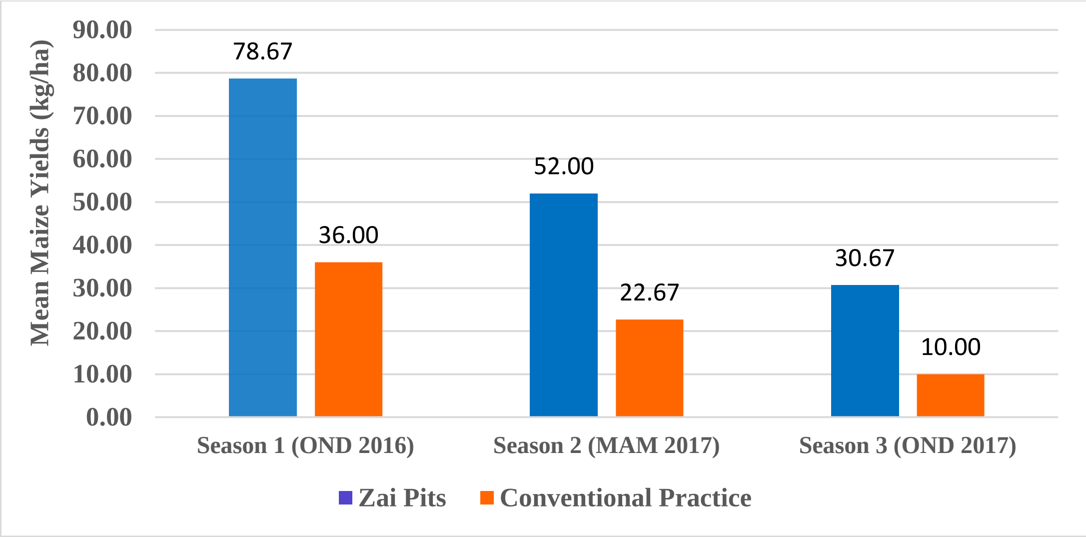


Figure 19: Mean maize yield from zaipits versus CVT Plots (2016/2017 Cropping Seasons)

The 2017 OND season recorded low crop yield for both Zai pits (30.67kg/ha) and CVT (10kg/ha). It was imperative to note that higher maize yield was recorded from the zai pits model than in the CVT plots during all the three cropping seasons. Table 33 shows the ANOVA results obtained to show the significance of the differences in the mean maize yield obtained from the two farming methods.

Table 33: ANOVA for mean yield of maize (Zai pits vs. CVT)

Season	F-Statistic	P-Value	F-Critical
OND 2016	46.55	0.00*	7.71
MAM 2017	25.67	0.01*	7.71
OND 2017	31.00	0.01*	7.71

** Significance level, α = 5%*

The ANOVA results show that in the three cropping seasons the computed F statistic values were all greater than the critical F statistic (7, 46; 7,25; 7;31) and the P values were all less than the test significance level (P<0.05). The null hypothesis of equality of means was therefore rejected for all seasons, implying that the difference in the mean maize yield was statistically significant under the Zai pits and CVT methods. With observation that the maize yields under Zai pits were higher than in the CVT over the three cropping seasons, a conclusion is drawn that Zai pits has a potential to significantly achieve higher maize yield thus providing greater food security and better incomes for smallholder farmers in the study area.

Similar results which showed that zai had potential to increase crop yield were demonstrated by a study conducted by Sawadogo (2011). The results of the study which was conducted in Northwestern Burkina Faso over three rainy season showed that use of zai in sorghum production led to an increased yield from 319-642kg/ha (without zai) to 975-1600kg/ha with zai. The study further established improved water infiltration in the zai plots and the soils were able to retain soil moisture for seven to ten days after rainfall when compared to control plots. There was a positive impact on soil fertility as there was increased content of carbon, nitrogen and phosphorus as well as other chemical parameters. By the fact that some soils in Yatta are of low fertility and degraded coupled with increased rainfall shortage and variation adoption of zai pits by majority smallholder farmers will indeed be a sure way towards land restoration and overcoming impacts posed by climate variability and change.

Summary of Findings

The CSA models that were tested for integration in smallholder farmers' practices demonstrated a potential for improving maize and greengram yield. Results obtained showed that use of both CA and zai pits models enhanced yield for the test crops in all seasons compared to the CVT practice. In all cropping seasons, the recorded maize yield under CA was higher when compared to the CVT method with statistically significance set at 5%. Similarly, maize grown under zai pits model yielded higher during all the three cropping seasons with the difference in the mean maize yield being statistically significant ($P<0.05$) under the Zai pits and CVT methods. Additionally, the green gram crop grown under CA yielded higher mean yield compared to the CVT method except for the mean yield of green gram during the MAM season of 2017.

These results show that the CSA models tested under this study have proven benefits to enhance crop yield for smallholder farming systems when compared to the CVT practices. This clearly demonstrates that adoption of the tested CSA options will enhance smallholder farmers' crop productivity and resilience in the face of climate change. It therefore demonstrates the need for continuous farmers' engagement to build their knowledge and capacity on benefits of the CSA approaches. It is thus critical to upscale adoption of the tested CSA practices in smallholder farming systems to enhance sustainable crop production which will alleviate food insecurity, poverty levels and malnutrition.

CHAPTER NINE: SYNTHESIS AND DISCUSSION

Climate change has probably become one of the most complex environmental and societal challenges undermining progress towards poverty eradication, food security and sustainable development especially in the developing World. It has been implicated to pose a considerable drawback to most critical economic sectors which mainly depend on natural resources such as agriculture, fisheries, livestock, forestry and tourism. In Kenya agriculture sector has been hardly hit which calls for geared focus on enhancing adaptation options in order to alleviate potentially impacts posed by changing climate to crop productivity.

This study primarily analyzed rainfall and temperature trends over a 32-year period in Machakos County. Results portrayed increasing trends in the mean of T_{max} and T_{min} annual and monthly temperatures over the analysis period. The statistical significance of the increasing trends were verified by the Mann K test which showed that statistically significant trends ($P<0.05$) were detected in the T_{max} and T_{min} annual and seasonal temperatures apart from the T_{max} trends during the MAM season which were not statistically significant ($P>0.05$). The findings relate to other findings which have shown that temperatures in Africa have inclined to increase faster than the global average temperatures (Niang *et al*., 2014; Engelbrecht *et al*., 2015). It was observed that the absolute increase in T_{min} over the period (1983-2014) was higher for both annual and seasonal time scales which concurs with other reports that have shown that T_{min} (night-time) have continued to depict a warming trend in the Greater Horn of Africa (GHA) (Omondi *et al*., 2014; Engelbrecht *et al*., 2015).

Analysis of the rainfall trends showed that the area is characterized by a bimodal rainfall with two distinct rainfall seasons (OND and MAM) in a year. The results indicated that the average monthly rainfall during the OND season was slightly higher as compared to the MAM season however the monthly rainfall trends were not statistically significant ($P>0.05$). On the other hand, seasonal rainfall trends showed that OND season recorded slightly higher rainfall than the MAM season with seasonal rainfall trends for both seasons showing statistically significant trends ($P<0.05$). The results further showed that the quantity of rainfall received in the area was extremely inconsistent while exhibiting increasing trends in the two rainy seasons. The annual rainfall trends depicted increasing trends with an erratic rainfall pattern over the 32-year period. The increasing annual and seasonal rainfall trends could be attributed to projection models which have shown that there is a projected increase in mean rainfall by more than ~10% in the Kenyan ASALs and a general wetter climate for East Africa (Shongwe *et al*., 2011; Yang *et al*., 2014). Furthermore, some research has also indicated that increase in rainfall has shown some insignificant results over East Africa apart from some areas around Somalia and western Ethiopia (Hoscilo *et al*., 2014). However, seasonal rainfall observations over East Africa show that rainfall has become variable and inconsistent with some observations showing declining rainfall trends over some parts of Kenya and the GHA (Lyon and DeWitt, 2012; Omondi *et al*., 2014; Liebmann *et al*., 2014; Rowell *et al*., 2015). Other results also show contradictory findings for instance Niang *et al*. (2014) affirms that variability and a decrease in rainfall amounts has been reported in Africa over the last three decades.

Comparison of farmers' perceptions with the observed temperature and rainfall trends in the area showed some varied results for both rainfall and temperature trends although some similarities were evident for the temperature trends. Perceptions obtained from farmers' showed that seasonal rainfall trends had decreased which is against the analyzed rainfall trends which showed increasing trends in seasonal rainfall. On the other hand, majority farmers' stated a variation in seasonal rainfall timings and decreased duration of seasonal rainfall which agrees with observed seasonal rainfall over East Africa and over some parts of Kenya which showed that rainfall has become variable and inconsistent with declining rainfall trends as well as amount (Lyon and DeWitt, 2012; Liebmann *et al*., 2014; Omondi *et al*., 2014; Rowell *et al*., 2015). On the other hand, farmers' perceptions on temperature trends were in agreement with the observed trends since majority respondents indicated that daytime temperatures had increased while the number of cold days had decreased over a 5-year period. This concurs with IPCC (2007a) report which showed that in most of the land areas there was an increase in warmer and fewer cold days and nights coupled with warmer and more frequent hot days and nights.

Research has shown that year-to-year variation in crop yield is usually related to weather fluctuations (Edeh *et al.*, 2011). IPCC (2007b) report indicates that in most African countries, yield of rainfed crops could be reduced by half by 2020. This study sought to determine the degree to which climate variables had impacted maize and beans yield. Results obtained showed that there was a considerable direct association between crop yield and rainfall trends where years with lowest average seasonal rainfall depicted low yield for maize and beans. According to Mburu *et al*. (2014), rainfall is an important climate parameter towards sustainable crop productivity under rainfed agriculture. It is therefore important to note that seasonal rainfall variability greatly affects availability of soil-water to crops thus posing risks to crop production. An analysis of rainfall variability in Yatta by Mburu *et al.* (2014), showed a steady increase in rainfall coefficient of variation indicating that variation in rainfall patterns had increased steadily over the years which had directly impacted negatively on crop production. The findings of this study indicated that an increase in T_{max} resulted to a decrease in seasonal mean yield of maize and beans which is a clear indication that a variation in temperatures, and, in most cases, extreme temperatures result in decreased crop yields. It is thus imperative to state that crop yield is highly determined by climate variability (Southworth *et al.*, 2000; Moriondo *et al*., 2011).It is thus imperative to conduct studies which demonstrate adaptation practices which need to be incorporated into farming systems to boost crop productivity and enhance resilience of smallholder farmers. In the context of the analyzed data showing decreased crop yield over time against changes in climate variables coupled with farmers' indication that they had experienced increased food insecurity and an increase in droughts in the area, the objective of this study to integrate CSA options in smallholder farmers' cropping systems was thus justifiable.

Understanding farmers' uptake and integration of adaptation strategies is essential in supporting and directing them towards adopting relevant and sustainable coping and adaptation strategies that are specific to their local site and requirements. Based on the fact that farmers had perceived climate variability and change in their locality and increased food insecurity, the study sought to explore strategies that farmers had put in place to adapt to the climatic changes which was useful to guide and build their adaptive capacity with a focus to integrate and uptake CSA approaches. There are diverse means of building farmers' adaptive capacity including but not limited to: building capacity of farmers and institutions, soil, water and crop management, knowledge sharing and dissemination, local adaptation planning, enhancing social safety nets and provision of agricultural insurance. Although several studies have explored which farmers' have integrated into their farming practices as a way of adapting to the changing climate, the studies did not analyze the extent to which the adaptation strategies had improved farmers' ability to deal with the experienced climatic changes. This study bridged this gap by focusing on farmers' adaptation strategies with focus on crop, water and soil management strategies and establishing the extent to which the adaptation strategies had enhanced farmers' ability to cope with climatic changes. Results showed that some of the crop management practices which greatly improved farmers' ability to cope with experienced climatic changes were; use of drought tolerant varieties, crop diversification and use of certified seeds. That is one of the considerations taken into account to use certified seed during the demonstration trials. For soil management strategies, use of inorganic fertilizers and farm yard manure emerged as the mostly adopted strategies and which had to a great extent improved farmers' ability to cope with the experienced changes. On water management strategies, water conservation was implicated to have improved farmers' ability to cope with changing climate to a great extent followed by water harvesting. On the other hand, use of irrigation and digging of boreholes and wells showed a low rate of adoption as well as a low extent of improving farmers' ability to deal with the changes.

In view of the adaptation strategies that the study had identified to improve farmers' ability to deal with climatic changes and which formed basis for use of farmers' indigenous knowledge, the study then sought to incorporate scientific knowledge towards building farmer's adaptive capacity with a focus to integrate CSA approaches. The process was facilitated through consultation forums where capacity building and farmers' sensitization was done. Several stakeholders were also incorporated which was effective in building synergy towards formulating a viable CSA strategy for the community. In order not to re-invent the wheel the approach was to integrate practices that were already at farmers' disposal and had proven potential to improve crop yield in a sustainable manner. When the selected CSA options (CA and Zai pits) were tested in comparison to the conventional practices, they proved to have a potential to increase maize and greengram yield. The results demonstrate that integration of the CSA options into smallholder farming systems is a viable option towards attaining food security and increased resilience.

CHAPTER TEN: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Results from the analysis of the historical climate data revealed increasing trends in annual temperature (T_{min} and T_{max}) which concur with farmers' perceptions of increasing daytime temperatures and number of hot days over the last five years. However, the analysis showed increasing rainfall trends contrary to farmers' perceptions of decreasing seasonal and annual rainfall trends. The MK test revealed statistically significant rainfall and temperature trends. The noted changes in climate patterns imply that sustainable crop production is becoming a challenging task if farmers continue with 'business as usual' farming models. Farmers' perceptions show there is climate variability in the area with reported occurrence of climate indicators such as late-onset and early cessation of rainfall, increased incidences of drought, food insecurity and drying of seasonal rivers. There was a significant direct relationship between the dependent variable (crop yield) and predictor variables (rainfall and temperature) with years with lowest average seasonal rainfall depicting low crop yield. Additionally, an increase in minimum and maximum temperature resulted to a decrease in seasonal mean yield of maize and beans which is a clear indication that a variation in temperatures, and, in most cases, extreme temperatures results in decreased crop yields. It is thus imperative to state that crop yield is highly influenced by changes in climate change variables. Although farmers had adopted several on-farm adaptation strategies, the adoption levels remained low with water management strategies recording higher adoption rates. The farmers' ability to adopt the adaptation strategies was greatly influenced by their experience on climate change impacts and their perception of the ability of the adaptation strategies to improve their adaptation capacity. Tested CSA options (CA and Zai pits) proved potential towards increasing maize and green gram crop yield in comparison to the conventional practices.

Recommendations

Based on its findings, this study puts forth the following recommendations:

1. The scientific knowledge generated from the long-term climate data analysis is critical in guiding an effective decision-making process and execution of viable policy responses for long-term climate risk management in Kenya's ASALs and other regions in Africa. The responses should focus on adaptation approaches that would counter the risks from the perceived changes in climate as well as noted climate trends and variability.

2. To inform policy decisions for sustainable adaptation responses calls for integration of farmers' indigenous knowledge and their experiences on changes in climate parameters with data from meteorological records. Such adaptation responses should include provision of climate advisory services and reliable weather forecasts which can inform on the optimum crop growing windows thus minimizing losses from unplanned seasonal calendars.

3. To minimize the effects of climate variables on crop yield, farmers should focus on transformative adaptation which requires making changes in farming systems. Such changes include use of drought-tolerant crops and/or crop varieties with shorter growing periods that would complement the shortened rainy period. Additionally, water management strategies, such as water harvesting, would play a critical role in harnessing available and unutilized rainwater for use during the dry seasons.

4. To enhance adoption and upscaling of adaptation strategies (crop, soil and water) which have shown ability to improve farmers' adaptation capacity calls for measures to overcome adoption and implementation barriers while ensuring alignment of policies, programs and institutional support systems. Governments and other stakeholders should consider more investment in infrastructure and expertise to enhance the development and implementation of water, crop and soil technologies that could offer the needed solutions.

5. To improve innovation and technology transfer, a systems approach that allows farmers' integration into the research design and implementation, while respecting local knowledge and skills, must be embraced. This will support effective integration, adoption and upscaling of conservation agriculture and zai pits which have shown potential to increase crop yield and resilience of smallholder farmers.

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APPENDICES

Appendix 1: Household Survey Questionnaire

I am a researcher from the University of Nairobi carrying out my academic research on "Climate-smart agriculture options for improved resilience and food security among smallhoder farmers in Yatta sub-County, Machakos County, Kenya". The information you provide will be used solely for research purposes and will be treated with utmost confidentiality.

Date: ___________________________ Village: ____________________________

Location of Household in GPS Coordinates

Latitude (N/S) _____________________ Longitude (E/W) ______________________

Elevation (m.a.s.l) ____

	CODE (Mark N/D if the information is not available)	RESPONSE
DEMOGRAPHIC PROFILE		
A1. Gender of the respondent	Male 2. Female	
A2. Are you the household head?	Yes 2. No	
A3. If the answer in A2 above is No, what is the gender of the household head?	Male 2. Female	
A4. How old are you? (years)	15-24 2. 25-34 3. 35-44 45-54 5. >55	
A5. How long have you lived in this community?	<1 year 2. 1 – 5 years 5 – 10 years 4. 10 – 15 years 5. 15 – 20 years 6. 20 – 25 years 7. 25 – 30 years 8. >30 years 9. Not a resident (Indicate where from)	
A6. How many members are currently living in your household?	1-3 2) 4-6 3) 7 and above	
A7. What is your highest level of education	Primary school Secondary School Tertiary / College University No formal Education Other (Please specify)	
A8. What is your **main** source of household income (**Indicate only one**)	Crop farming Livestock farming 3. Off-farm employment 4. Government employment	

	Business 6. Pension 7. Government Welfare 8. Other (Specify)	
B. AGRICULTURAL PROFILE		
B1. Does your household undertake crop farming?	Yes-Rain-fed (R) 2. Yes-irrigated (I) 3. Yes R&I (both 1 &2) 4. No	
B2. What major food crop(s) have you grown in the last 5 years	1. Maize 2. Beans 3. Millet 4. Cowpeas 5. Pigeon peas 6. Sorghum 7. Green grams 8. Cassava 9. Dolichos 10.Sweet potatoes	
B3. Has your overall crop yield increased in the last 5 years?	1. Yes 2. No	
B4. If the answer in B4 above is Yes, what do you think has led to the increased yields? (Multiple responses)	1. Use of drought tolerant varieties 2. Use of certified seeds 3. Early planting. 4. Use of inputs (fertilizer, pesticides) 5. Use of conservation agriculture 6. Practice Monocropping 7. Use of farm-yard/ compost manure 8. Use of Zai pits (Tumbukiza) 9. Favorable weather conditions (more rainfall)	
B5. If your answer in B4 above is No, what do you think is the cause for decreased crop yield? (Multiple responses)	1. Pest(s) outbreak 2. Less favorable weather conditions (Inadequate rainfall, Excessive rainfall, high/low temperatures, strong winds etc) 3. Less access to agricultural inputs (certified seeds, fertilizer) 4. Inability to grow crops previously grown 5. Decrease in soil fertility 6. Other reason (Please specify)	
B6. Do you use fertilizers	1. Yes 2. No	
B7. If your answer in B7 above is Yes, what type of fertilizer have you used in the last 2 years?	1. Animal manure 2. Chemical fertilizer (DAP/NPK/CAN) 3. Compost manure 4. Organic fertilizers 5. Other (Please specify) 6.	
PERCEPTIONS TO CLIMATE VARIABILITY AND CHANGE		

C1. From your experience, have you noticed any changes in climate in this locality in the past 10 years?	1. Yes 2. No	

C2. Please state your response on the following statements which relate to climate variability and change indicators

Please tick (✓) your appropriate answer in the scale of 1-5, where 1=Strongly disagree, 2= Disagree, 3= Not sure, 4= Agree, 5= Strongly agree

	1	2	3	4	5
Trends of seasonal rainfall have decreased					
Rainfall timings have changed					
Incidences of drought have increased					
Food insecurity has increased					
Rainfall patterns have become unpredictable					
Seasonal rivers have disappeared					
Pest incidences have increased					

C3. Please state your response in regard to any changes you have noted in seasonal rainfall over the last 5 years?

Please tick (✓) your appropriate answer in the scale of 1-5, where 1=Strongly disagree, 2= Disagree, 3= Not sure, 4= Agree, 5= Strongly agree

	1	2	3	4	5
Duration for short rains (OND) has decreased					
Duration of long rains (MAM) has decreased					
Duration of short rains (OND) has increased					
Duration of long rains has (MAM) increased					
Intensity of rainfall during long rains (MAM) has increased					
Intensity of rainfall during short rains (OND) increased					
Onset of seasonal rainfall has become unpredictable					
Cessation of seasonal rainfall has become unpredictable					
There is increased occurrence of untimely rainfall					

C4. Please state your response in regard to any changes you have noted in temperatures over the last 5 years?

Please tick (✓) your appropriate answer in the scale of 1-5, where 1=Strongly disagree, 2= Disagree, 3= Not sure, 4= Agree, 5= Strongly agree

	1	2	3	4	5
Daytime temperatures have increased					
a) Daytime temperatures have decreased					
b) Number of hot days has increased					
c) Number of hot days has decreased					
d) Number of cold days has increased					
Number of cold days has decreased					

C5. Please state your response in regard to any changes you have noted on occurrence of dry periods over the last 5 years

Please tick (✓) your appropriate answer in the scale of 1-5, where 1=Strongly disagree, 2= Disagree, 3= Not sure, 4= Agree, 5= Strongly agree

	1	2	3	4	5
Duration of dry periods has become longer					
Duration of dry periods has become shorter					
Frequency of dry periods has increased					
Frequency of dry periods has decreased					

CLIMATE CHANGE IMPACTS TO THE COMMUNITY

D1. Which of the listed climatic event (s) has significantly affected your household during the last 5 years? (Multiple responses)	1. Drought 2. Excessive rainfall/Floods 3. Lightning 4. Landslides 5. Strong Winds 6. Frost 7. Crop Disease 8. Heat waves 9. Other (specify)	

D2. In the list in the table below, please state how the experienced climatic event (s), stated in D1 above, has affected your family/community and/or your farming activities

Please tick (✓) your appropriate answer in the scale of 1-5, where 1=Not at all, 2= Less extent, 3= Moderate extent, 4= Large extent, 5= Very large extent

	1	2	3	4	5
Decline in crop yield					
Loss of income					
Loss of assets					
Loss of entire crop					
Decreased availability of water					
Death of livestock					
Decline in livestock production					
Increase in food prices					
Food Shortage					
Damage to infrastructure (e.g. roads, canals,					

D3. In the list below, indicate to what extent the measure improved your ability to cope with the experienced climatic event

Please tick (✓) your appropriate answer in the scale of 1-5, where 1=Not at all, 2= Less extent, 3= Moderate extent, 4= Large extent, 5= Very large extent

	1	2	3	4	5
Migrated to a new area					
Received government donations/ relief food					

Assistance from friends/relatives						
Sold asset (land, house, livestock)						
Borrowed (bank, private money lenders, relatives and friends)						
Sought off-farm employment						
Household member migrated to other rural area						
Reduced household food consumption						
Reduced household expenditure						

FARMERS' ADAPTATION STRATEGIES TO CLIMATE VARIABILITY & CHANGE

E1. Have you made any changes in your farming practices in the last 10 years?	Yes 2. No (If No, move to E6)	
E2. From whom did you get information on how to implement the change(s)?	1. Relative 2. Neighbor 3. Project/NGO 4.Agriculture extension officer 5. Media (radio, newspaper, chief barazas) 6. Other (specify)	

E3. In the list of measure (s) in relation to crop management, indicate what extent its adoption has improved your ability to deal with climate changes
Please tick (✓) your appropriate answer (only under measure you have adopted) in the scale of 1-5, where 1=Not at all, 2= Less extent, 3= Moderate extent, 4= Large extent, 5= Very large extent

	1	2	3	4	5
Changing planting dates (Early planting, Late planting)					
Change in crop variety –(switch from maize to sorghum etc)					
Planting drought tolerant crop varieties					
Crop diversification (additionally growing fruits, vegetables)					
Use of certified seeds					
Crop rotation					
Monocropping					
Early planting					
Growing orphan crops (cassava, sorghum, sweet potatoes)					
Agroforestry					

E4. In the list of measure (s) in relation to water management, indicate what extent its adoption has improved your ability to deal with climate changes

Please tick (✓) your appropriate answer (only under measure you have adopted) in the scale of 1-5, where 1=Not at all, 2= Less extent, 3= Moderate extent, 4= Large extent, 5= Very large extent

	1	2	3	4	5
Water harvesting (sand dams, tanks, ponds)					
Water conservation (Terraces, Zaipits, furrows, trenches)					
Use of irrigation system					
Digging well/borehole					

E5. In the list of measure (s) in relation to soil management, indicate what extent its adoption has improved your ability to deal with climate changes

Please tick (✓) your appropriate answer (only under measure you have adopted) in the scale of 1-5, where 1=Not at all, 2= Less extent, 3= Moderate extent, 4= Large extent, 5= Very large extent

	1	2	3	4	5
Use of conservation agriculture (CA)					
Mulching					
Retaining crop residues in the farm					
Use of farm-yard manure/compost					
Use of artificial fertilizers (CAN, DAP, NPK)					
Use of organic fertilizers					
Afforestation (Tree planting)					
Re-afforestation (Tree re-planting)					

E6. Please indicate your view on how the listed factors have influenced your inability to implement change in your farm

Please tick (✓) your appropriate answer in the scale of 1-5, where 1=Strongly disagree, 2= Disagree, 3= Not sure, 4= Agree, 5= Strongly agree

	1	2	3	4	5
Not realized reason for change					
Limited money/capital					
Limited credit services					
Limited equipment/machinery					
Failure to access extension services (information)					
Limited inputs (e.g. fertilizer/seeds)					
Labor shortage					

E7. Do you belong to any social group?	Yes 2. No	
E8. If yes in E5, what type of social group?	Farmers' association Youth group	

	Women's group Religious group Credit /Saving group Community Based Organization Water resource users' association Staff association Other (Specify)	
E9. What type of help do you get from the group?	Loan/Credit services Livestock/Poultry Marketing of farm Produce Technical/Equipment Support Farm inputs (Seeds, fertilizer, pesticides) Tree Saplings (for agro-forestry) Food aid Farming support (Land preparation, Harvesting, weeding) Building and maintenance of terraces Other (Specify)	
E10. When faced with adverse weather effects, do you get any assistance from the government?	Yes 2. No	
E11. If your answer in E8 above is yes, what kind of support do you get from the government?	Farm inputs Relief food Training on adaptation approaches Other (please specify)	

THANK YOU VERY MUCH FOR YOUR ANSWERS!

Appendix 2: Focus Group Discussion guide

Purpose of the FGDs

The FGDs are meant to engage smallholder farmers in Ndalani Ward through participatory interaction in order to gain a deeper understanding on impacts of climate change and variability on their livelihoods, their perceptions on climate change and variability and their adaptation strategies.

Objectives of the FGDs

To understand farmers' perceptions to climate change and variability, impacts of climate change and variability farmers' adaptation strategies.

Structure of the FGDs

A total of eight (8) FGDs with ten (10) participants each shall be conducted in eight (8) villages in the study area while segregating the participants by gender.

Design of the FGDs

- The FGDs will mobilize village elders/key-informants to select and identify knowledgeable and experienced smallholder farmers for both women and men groups.
- The FGDs facilitation team will consist of at least two members including a facilitator (who will be responsible for logistics) and a Rapportuer.

Logistical considerations:

- A venue for the activity shall be chosen where the atmosphere will be less formal and shall be close to the field.
- Efforts shall be made to minimize distractions such as noise from passing vehicles or mobile phones.
- The participants shall be invited and informed about the purpose and the time it will take beforehand.
- There will be separate meetings for men and women.
- Each team member will be provided with a copy of the FGD guide with a list of discussion themes.
- An outline of the meeting shall be written on a board to enable each participant to see the progress of the discussion.
- Preparation of supplies and materials (pens, paper, writing board, etc) shall be done in advance.
- At the start of the meeting a list of participants and some basic information shall be obtained: full name, age, gender, village and sub-location, mobile number.
- The researcher shall explain how the data will be used and how a report will be provided to them or the wider communities.

Discussion Themes:

The FGDs shall consist of three themes: farmers' perception on climate change and variability; impacts posed by climate change and variability and farmers' adaptation strategies. During the sessions, times shall be indicative since the topic shall be addressed in an explorative manner. The facilitator shall guide the discussion and keep time

Agenda

Theme	Time
Introduce the project, facilitators and participants Explain the purpose of the discussion Introduce the different themes	30 min
Theme 1: Community's perception to climate change and variability (Diagramming community's perception on climate change) List some of the indicators for climate change and variability? 1. List and rank traditional/indigenous indicators which were used 20 years ago to determine/predict onset of rainfall in Yatta 2. List and rank some of the indicators that are still in use for determination of on-set of rainfall 3. List and name extreme events (drought/famine) that have occurred in Yatta over the years- local name and year	45min
Theme 2: impacts of climate change on community's livelihood Food security status, water sources (rivers), crop production, pests and diseases, soil fertility List the years when drought was experienced in your locality List and rank ways in which climate change has affected your livelihoods Have you experienced any new crop diseases in the locality? If Yes in No. 3 above list the name of the diseases and their impacts	45min
Theme 3: Community's adaptation practices to climate changes To answer experience based knowledge and lessons the community has used to recover, adapt and manage agricultural risks and climate change related calamities 1. List and rank farming practices you have adopted in your farm in the last ten (10) years to increase crop production 2. Indicate from whom you got information on the need to implement the change (adopt the new farming practices) 3. If you have not implemented any change in your farming practices, list and rank the reasons why this has been so 4. List and rank the type of support you receive from social group(s) towards improving your farming activities or income 5. List crop varieties that you have selected to become more resistant to climate change effects 6. Mention coping strategies which you think will be useful to adapt to climate change that you are not yet using either due to the cost or expertise	60 min

7. List (if applicable) any organizations which assist the community during drought/famine? 8. Does the government assist you during drought/famine? 9. If your answer is yes in No. 8 above, list the kind of support you get from the government 10. List what you think the government should do more to reduce the effect of climate change and variability 11. List any barriers you have experienced towards implementing adaptation to climate change and variability	

Closing session

A summary of findings shall be provided for each theme in order to capture a few statements.

Appendix 3: List of Traditional/Indigenous Indicators

No.	Indicators used Before	Indicators Still in Use
1.	Behaviour of trees - Emerging of new leaves on some specific trees, flowering of certain trees, shedding of leaves of some trees.	Behaviour of trees - Emerging of new leaves on some specific trees, flowering of certain trees, shedding of leaves of some trees.
2.	Traditional forecasters	
3.	Extra activeness of animals –cows, birds, chicks	Extra activeness of animals (young calves), birds and chicks
4.	Noise from certain birds and insects which usually came from the eastwards "mataa mwaka" "ivutavutilya", Bees and butterflies moved from eastwards to the westwards, playing mandis used to fly in a special way	Noise of birds "ivutavutilya"
5.	Clearing of mountain peaks (Mt. Kenya)	
6.	Snowing on mountains	
7.	Unusual high temperatures	Unusual high temperatures
8.	Lightning and thunder	
9.	Very heavy winds known as "kilingi" – north western monsoon winds	Heavy and strong winds "kilingi" from certain eastward direction
10.	Appearance of dark clouds in the sky	